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Economic Geology

and the

Bulletin of the Society of Economic Geologists

CONTENTS

Structural and Economic Characteristics of New England Mica Deposits ..... *E. N. Cameron, D. M. Larrabee, A. H. McNair, J. J. Page, V. E. Shainin and G. W. Stewart* 369

The Chicote Tungsten Deposit, Bolivia ..... *Federico Ahlfeld* 394

Structural and Stratigraphic Control of Zinc Deposits in East Tennessee ..... *Johnson Crawford* 408

The Cult of the Indeterminate. Whither "Replacement"? ..... *W. James Bichan* 416

Books Received ..... *Ralph E. Digman* 425

Scientific Notes and News 427

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STRUCTURAL AND ECONOMIC CHARACTERISTICS OF NEW ENGLAND MICA DEPOSITS.

E. N. CAMERON, D. M. LARRABEE, A. H. MCNAIR, J. J. PAGE, V. E. SHAININ AND G. W. STEWART.[1]

CONTENTS.

Introduction 370
Acknowledgments 371
Previous work 372
Types of pegmatites in New England 372
Zoning in pegmatites 372
Muscovite in pegmatites 374
Types of mica deposits in New England pegmatites 374
  Wall-zone deposits 375
  Intermediate-zone deposits 380
  Pod deposits 385
  Fracture-controlled deposits 385
  Disseminated deposits 386
  Complex deposits 387
  Special types 388
Comparison of types 389
Applications to prospecting and mining 391
  Recognition of the type of deposit 391
  Recognition of productive pegmatites 391
  Mineralogical and structural indications 391
  Vertical variations in mica content and quality 392
  Exploration and development of mica deposits 392

ABSTRACT.

In connection with the intensive wartime exploitation of domestic mica deposits, the Geological Survey has been engaged in a comprehensive investigation of New England mica pegmatites. More than 200 pegmatites have been mapped and studied in detail and some hundreds of others have been given brief examination. The opportunity for pegmatite study has been unprecedented, and much new information on the characteristics of pegmatites has been obtained.

[1] Published by permission of the Director, U. S. Geological Survey.

Geologic analysis of pegmatites has helped to clarify the relationships between mica distribution and structural features and has led to a classification of mica deposits into basic types, of which five are especially important: wall-zone, intermediate-zone, pod, fracture-controlled, and disseminated. In some pegmatites, designated complex deposits, combinations of two or more of the basic types have been found. The different types are described and illustrated and their relative economic importance is shown by production figures. Analyses show clearly that certain types of deposits are far more productive than others and are far more likely to sustain profitable mining operations. Applications of current studies to mica mining, prospecting, and exploration are discussed.

INTRODUCTION.

THE urgent wartime need for high-quality sheet mica focussed attention on the vital and strategic importance of this mineral and aroused a keen interest in domestic sources of supply. As a consequence the languishing mica-mining industry was revitalized during the years 1942 to 1944 through government subsidy and other less direct methods of aid, so that during this period there were probably more mica mines operating in the United States than at any other single period in the history of the nation. This greatly increased activity, in turn, has provided an unprecedented opportunity to study the geological features of mica deposits and to obtain, for the first time, reasonably accurate data from a large number of deposits. The Geological Survey has been studying these aspects of the mica problem in each of the several mica-producing districts in the United States, and the present paper briefly summarizes the more cardinal and practical results of these studies as they relate to the mica deposits of the New England region.

More than 200 pegmatites have been mapped and studied in detail, and some hundreds of others have been given brief examination in the New England region (Fig. 1). Since the inception of the program, both mica- and beryl-bearing pegmatites have received attention, but the major part of the work has dealt with pegmatites containing sheet muscovite. The present paper discusses some of the results of these studies, with special reference to New Hampshire and Connecticut pegmatites.

The investigations on which this paper is based were carried on under the supervision of H. M. Bannerman, and the technique employed was an outgrowth of his earlier work on pegmatites in New Hampshire.[2] Briefly, the methods followed are those long used in the investigation of mineral deposits —mapping on scales ranging from 10 to 80 feet to 1 inch, together with detailed analyses of internal and external structual features. Geologic features have been correlated with careful analyses of mineral recovery, quality, and costs of mining and processing.

In the mining industry pegmatites in general have a reputation for erratic structure and composition, but it has been recognized that in many pegmatites the distribution of muscovite and other commercial minerals obeys certain rules and that mica deposits can be classified on this basis. For New Eng-

[2] Bannerman, H. M.: Structural and economic features of some New Hampshire pegmatites. New Hampshire State Planning and Development Comm., Concord, N. H., 1943.

land mica deposits the present studies have so served to strengthen and extend existing classification that it can be used in evaluating deposits. In particular, the relations of mica deposits to structural features have been so clarified as to be applicable directly to problems of mining, exploration, prospecting, and estimating reserves.

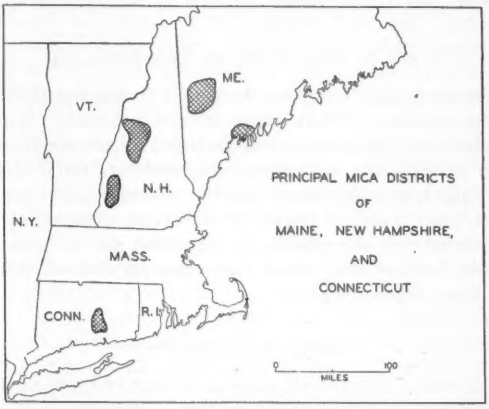

FIG. 1.

ACKNOWLEDGMENTS.

The work upon which this paper is based was carried on in close cooperation with Colonial Mica Corporation, agent for Metals Reserve Company, and the writers are indebted to the officials of this company, especially to Mr. Orrin P. Peterson, New England Manager, for generously contributing many pertinent production data. Grateful acknowledgment is made also to the mine operators and owners throughout the region for their unfailing courtesy, kind interest, and cooperation, without which the work could not have been done.

In this paper zoning in pegmatites is briefly described, with particular reference to New England mica pegmatites. Concepts on which the description is based are the outgrowth of discussions carried on by the authors with R. H. Jahns and L. R. Page, representing parties engaged in similar investigations in other pegmatite districts. The classification originally presented for New England mica deposits by the authors [3] has been modified in certain respects in accordance with these concepts.

The authors wish to express their thanks to Dr. Gerald F. Loughlin, of the Geological Survey, for numerous suggestions based on a critical reading of the manuscript.

[3] Cameron, E. N., Larrabee, D. M., McNair, A. H., Page, J. J., Shainin, V. E., and Stewart, G. W.: Structural and economic characteristics of New England mica deposits. U. S. Geological Survey, press bulletin, Washington, Sept., 1944.

PREVIOUS WORK.

A report on New England mica deposits by D. B. Sterrett [4] was published in 1923, and one on New Hampshire mica deposits by J. C. Olson [5] was published in 1942. Both reports contain much valuable information on the characteristic features of mica deposits and of individual mines. They have served, together with Bannerman's report,[6] as background for the present studies.

TYPES OF PEGMATITES IN NEW ENGLAND.

The pegmatites studied exhibit a variety of forms, but dikes, sheets, and lenses are most common. Their range in size is broad. Some pegmatites are rather uniform in thickness and in attitude; others are markedly irregular. Common irregularities are pronounced bends or "rolls" of the walls that usually pitch roughly parallel to one another within a given pegmatite. The direction of pitch is commonly related to structural elements of the enclosing rocks. Determination of the pitch is an important part of structural analysis of mica deposits, because many mica shoots are parallel or related to "rolls" or changes in their degree of pitch.

ZONING IN PEGMATITES.

Nature of Zoning. Pegmatites show a number of types of internal structures. Many appear essentially massive; that is, they are essentially uniform mixtures of their component minerals. In others the minerals are distinctly grouped into structural units of contrasting composition or texture that have a systematic arrangement with respect to the walls of a given pegmatite body. Pegmatites of this type are "zoned pegmatites," and the component structural units are termed "zones." The zonal arrangement appears in many cases to result from development of a pegmatite in successive stages, inward from its walls.

In ideal development, the zones of a pegmatite are successive shells concentric about an innermost zone, or "core." The configuration of the zones in a pegmatite body reflects the shape of the body in greater or less degree. Commonly, however, some of the zones within a given pegmatite are incomplete or discontinuous, and there are all gradations between complete zones and those that are developed only along one side or one end of a pegmatite body. These incomplete zones show a variety of forms, of which lenses, layers, and pods are the most common (Figs. 2, 4, 5, 12 and 16).

A zone is normally characterized by a specific mineral assemblage, and in the accompanying illustrations the names of abundant or characteristic minerals are used to designate zones. However, variations in mineral proportions are frequently found and these are responsible for striking variations present within certain zones.

[4] Sterrett, D. B.: Mica deposits of the United States. U. S. Geol. Survey Bull. 740, 342 pp., Washington, 1923.

[5] Olson, J. C.: Mica-bearing pegmatites of New Hampshire, a preliminary report. U. S. Geol. Survey Bull. 931-P, 45 pp., Washington, 1942.

[6] Bannerman, H. M., op. cit.

A sharp distinction between zoned and unzoned[7] pegmatites cannot be made. Gradations between them exist. Furthermore, zoning in pegmatites is three-dimensional, whereas most pegmatites are exposed only in two dimensions, and even then incompletely. Whether a pegmatite appears zoned or unzoned depends, to a considerable extent, on the part that happens to be exposed. If only a single zone is intersected by the topographic surface or by mine workings, the pegmatite will appear unzoned. In the Strickland quarry, for example, only the upper part of the Strickland pegmatite lens was exposed during earlier operations (Fig. 7) and, except for extremely narrow border zones, the pegmatite at this time must have appeared unzoned. Subsequent deeper operations have disclosed a striking zonal structure.

Significance of Zoning. The concept of zoning is fundamental to analysis of pegmatite structure and mineral distribution. Furthermore, zones in a pegmatite undoubtedly express variations in physico-chemical conditions during its formation—variations both from place to place within the body, and from stage to stage of its development. Zoning is likewise important from the practical standpoint. Few unzoned pegmatites in New England contain mica or other minerals in minable concentration. The bulk of pegmatite mineral production is from zoned pegmatites—from certain zones that are richer than others in mica, beryl, feldspar, or other commercial minerals. Except in narrow pegmatites, which must be mined in entirety, mining must ordinarily be restricted to the zone or zones that contain the minerals sought. The extent, shape, and trend of the productive zones are controlling factors in mining, exploration, and calculation of reserves, and a primary objective of geologic study is to provide the necessary information regarding the zones.

Relation of Zoning to Replacement. The role of replacement has been discussed by many investigators since the work of Schaller, Hess, Landes, Cook, and Müllbauer focussed attention on the problem.[8] Out of this work has grown the conception that pegmatite development is accomplished in two main stages—a primary, magmatic stage of intrusion and crystallization of a fairly simple pegmatite, and a later stage involving successive hydrothermal replacements.

Field evidence gathered during the present investigation tends to confirm the prevailing concept of two main stages in pegmatite development. However, it seems clear that in zoned pegmatites the early stage was more complex than has been generally realized. The zones which determine the fundamental

[7] In the strictest sense, none of the pegmatites examined are truly "unzoned." A narrow border zone is invariably present. In the present paper the term "unzoned pegmatite" is used, however, for any pegmatite which appears essentially homogeneous apart from the presence of a border zone.

[8] Schaller, W. T.: The genesis of lithium pegmatites. Amer. Jour. Sci., vol. 10, pp. 269–279, 1925.

Hess, F. L.: The natural history of pegmatites. Eng. and Min. Jour. Press, vol. 120, pp. 289–298, 1925.

Landes, K. K.: The paragenesis of the granite pegmatites of central Maine. Amer. Min., vol. 10, pp. 355–411, 1925.

Cook, C. W.: Molybdenite deposit near New Ross, Nova Scotia. Econ. Geol., vol. 20, pp. 185–188, 1925.

Müllbauer, F.: Die Phosphatpegmatite von Hagendorf i. Bayern. Zeits. Krist., vol. 61, pp. 318–336, 1925.

internal structures of most New England mica pegmatites and are the controlling element in mineral distribution appear in general to antedate the type of replacement discussed by the investigators cited above and evidently developed during the primary stage.

Whether the zones developed in open or closed systems, and to what extent fractional crystallization, convection currents, dynamic influences, and other factors played a part are matters for later discussion. In the simplest case, the process appears to have been deposition of successive concentric shells inward from the walls of the chamber.

It is not the intention of the writers to dismiss successive hydrothermal replacements as an unimportant process in the development of New England mica pegmatites. In some, later replacement has extensively modified or even obscured zonal structures. In most pegmatites field studies, however, have given no indication that the zones themselves were developed by hydrothermal replacement of pre-existing massive pegmatite.

MUSCOVITE IN PEGMATITES.

Muscovite mica occurs in all the pegmatites examined, but most of it is in crystals too small to yield trimmed sheet measuring at least 1 inch square. Even in muscovite books of adequate size, structural imperfections are invariably present that mar the books to greater or less extent. Sheet recovery after rifting and trimming is rarely as much as 10 per cent of the mine-run product, and 4 or 5 per cent is considered very satisfactory. In the following discussion the terms "sheet-mica zone" and "sheet-mica deposit" are used. These terms designate a zone or deposit containing muscovite books sufficiently large and sufficiently free from structural defects to yield full-trimmed sheet (1×1 to $1\frac{1}{4} \times 1\frac{1}{4}$ inches) and three-quarter trimmed sheet ($1\frac{1}{2} \times 2$ inches and larger) in quantities equal to 0.5 per cent or more of the mine-run product.

Interest in sheet mica is centered at present on those grades of sheet that are classified as "strategic" because they are needed for war purposes. To be accepted as "strategic," sheet mica must meet certain specifications as to quality, which is determined by freedom from air pockets and "stains" and by flatness. The sheet must also have an area of 1 square inch or more after defective parts have been trimmed off. Domestic strategic mica corresponds to India qualities ranging from "clear" to "heavy stained." [9]

TYPES OF MICA DEPOSITS IN NEW ENGLAND PEGMATITES.

For classification of mica deposits, the mode of distribution of the mica is the fundamental characteristic. On this basis five major types of sheet-mica deposits are recognized from present studies: wall-zone, intermediate-zone, pod, fracture-controlled, and disseminated. In general the types are distinct, but gradations are found here and there, and some pegmatites, here designated complex deposits, show combinations of two or more of the basic types. All but a very few of the deposits studied fall within this classification.

[9] The Mica Industry. U. S. Tariff Commission, Report No. 130, 2nd series, Washington, 1938.

Wall-zone Deposits.

In zoned pegmatites books of muscovite containing sheet mica are frequently concentrated in a zone lying along a wall or contact, but separated from the wall rock by a few inches or a few feet of barren, finer-grained pegmatite. In the Wadhams-Tucker deposit (Fig. 2), for example, sheet muscovite is found in a layer 1 to 3 feet thick separated from the hanging wall by a few inches of finer-textured border-zone material of similar composition. The remainder of the dike is virtually barren of sheet mica. Sheet-mica con-

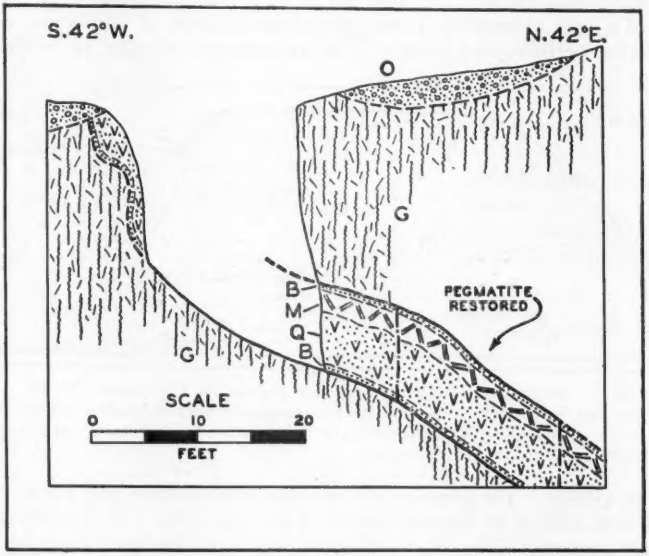

FIG. 2. Structure section of Wadhams-Tucker pegmatite, Alexandria, N. H. G. W. Stewart and H. Kamensky, April, 1944. G—Quartz monzonite gneiss; B—border zone; M—sheet-mucovite zone; Q—quartz-plagioclase-perthite zone; O—overburden.

centrations of this type are designated here as wall-zone deposits. In some pegmatite dikes, sheets, and lenses, wall-zone deposits are developed only along the hanging wall; in a few pegmatites they are developed only along the footwall. In others, the wall zone is present along both hanging wall and footwall and (in plan) may extend around one or both ends of the pegmatite body. In such pegmatites, however, the hanging wall and footwall parts of the zone may differ in persistence, in book mica content, in quality of mica, and in content of recoverable sheet of strategic quality. The difference may be sufficient to limit mining to the better of the two parts. Workable concentrations are more commonly found along the hanging wall than the footwall.

Wall-zone deposits are composed essentially of quartz, albite or oligoclase, and muscovite. The general absence of potash feldspar and biotite is noteworthy. These minerals occur in many pegmatites that contain wall-zone deposits, but are confined to the middle parts or cores of nearly all the pegmatites in which such deposits are at all well developed. In the Blister mine (Fig. 9), for example, both biotite and potash feldspar (microcline-perthite) are lacking in the wall zone, though abundant in other parts of the pegmatite.

In the pegmatite of the Sargeant mine (Fig. 3), sheet muscovite occurs almost solely along the troughlike bottom of a pegmatite. The mica is most abundant along the axis and west side of the trough and occurs near the bottom of a layer of medium-grained pegmatite composed of plagioclase, quartz, microcline-perthite, and biotite. The medium-grained zone is overlain by

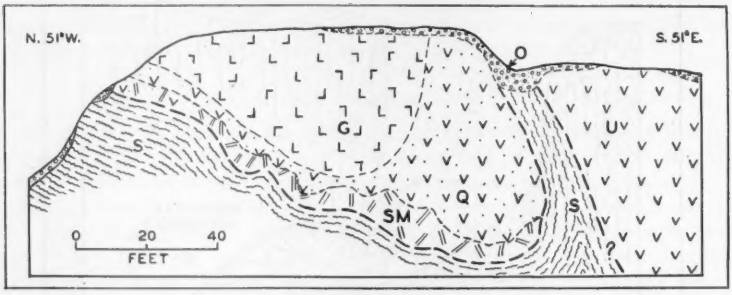

FIG. 3. Structure section of Sargeant pegmatite, Claremont, N. H. A. H. McNair and J. Chivers, August, 1943. S—quartz-mica-staurolite schist; SM—sheet-mica zone; Q—quartz-plagioclase-perthite zone; G—graphic granite; U—pegmatite undivided; O—overburden.

graphic granite. The presence of both microcline-perthite and biotite in the sheet-mica zone is an unusual feature of this pegmatite. In the Strickland-Cramer pegmatite (Fig. 7), a wall-zone deposit is developed along both the footwall and the hanging wall of a lenticular mass. The hanging wall part on the average is richer and more persistent than the footwall part and contains mica of higher average quality. In both zones the essential minerals are quartz, plagioclase, and book muscovite.

As most New England mica mines are shallow and have no great extent along the strike, data regarding the extent of wall-zone deposits are limited. In the Strickland-Cramer pegmatite the wall-zone deposit has a known strike length of 600 feet along the hanging wall and has been explored for as much as 170 feet down the dip. The deposit along the northwest wall of the Victory-Gilsum pegmatite has been worked for 1,100 feet along the strike and for 225 feet down dip. Though large compared to certain other types of mica deposits, known wall-zone deposits are not co-extensive with the pegmatites that contain them. In the lenticular Strickland pegmatite (Fig. 7), for example, the wall mica zone extends along the sides and bottom of the pegmatite lens, but is absent from the crest and south end of the lens. Similar relations

are shown in the Fellows mine, Wentworth, N. H., the Tolgate mine, Middletown, Conn., and others.

In other pegmatites the extent of the wall-zone deposit is related to a pronounced structural feature of the pegmatite walls. In the Ruggles mine, for example, the pegmatite terminates upward in a major southwestward-

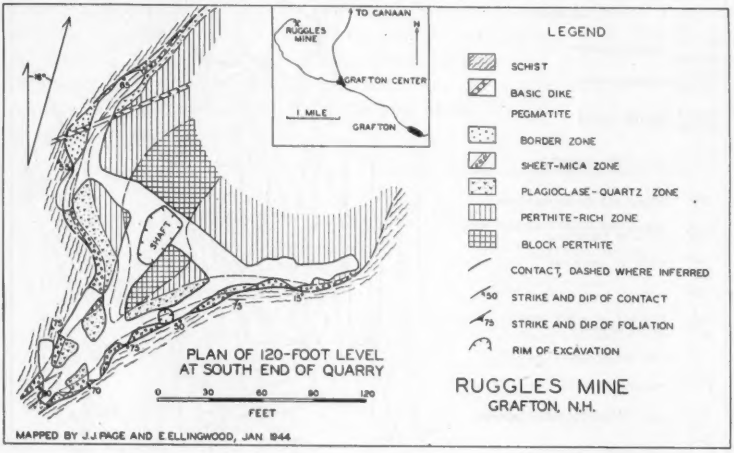

FIG. 4.

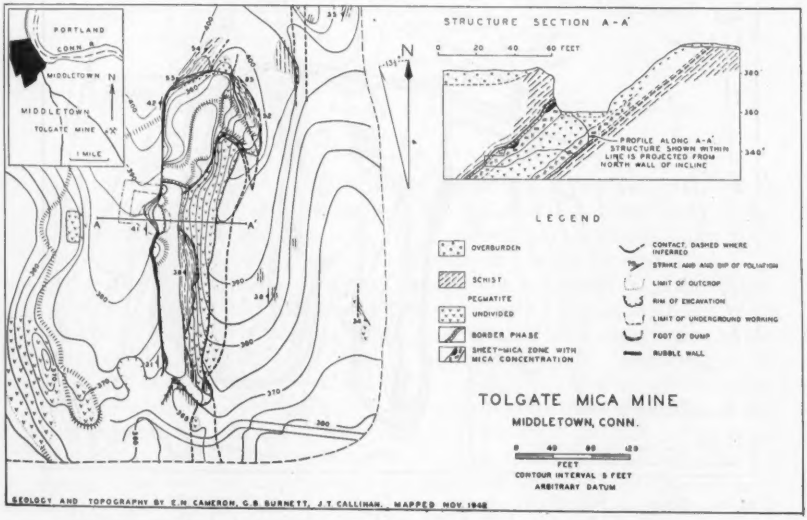

FIG. 5.

pitching apex or nose (Fig. 4), which is complicated by small rolls of the pegmatite contact. The rolls pitch roughly parallel to the apex. The wall-zone mica deposit is best developed in the vicinity of the apex, dying out downward and northeastward from it. Relations of this type may have a

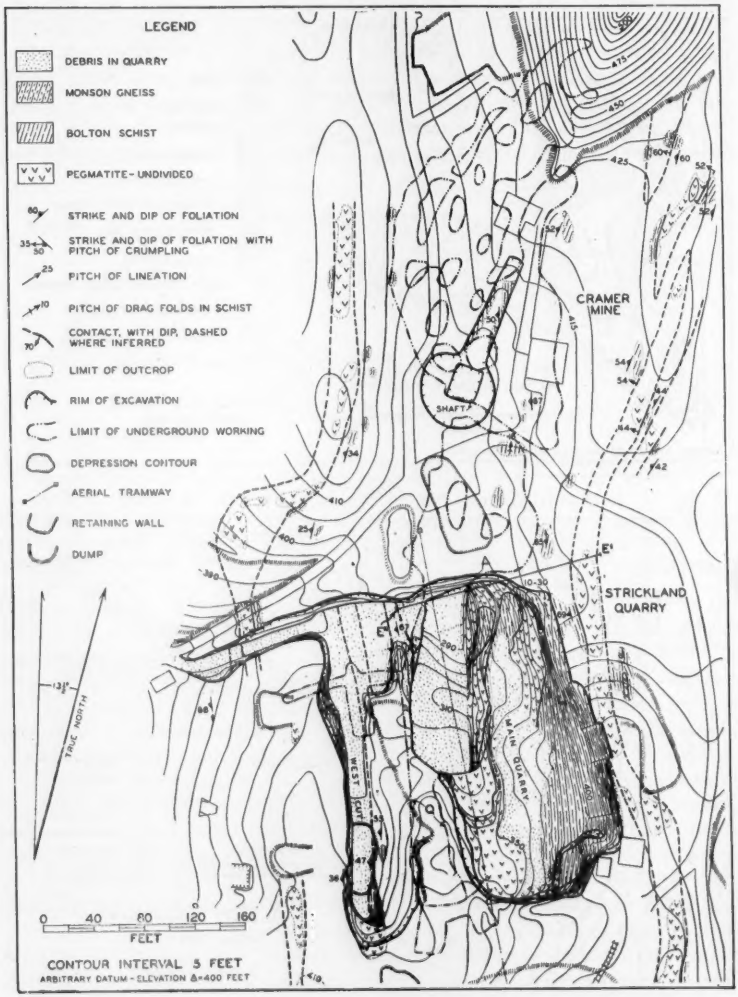

FIG. 6. Map of Strickland quarry and Cramer mine, Portland, Conn. E. N. Cameron, G. B. Burnett, J. T. Callihan, V. E. Shainin, J. J. Page, 1942–44.

controlling influence on mining and development and obviously enter into the estimation of reserves.

In well exposed wall-zone deposits, variations in thickness and richness of the zones usually show a systematic relation to structural features of the walls. Almost any pronounced structural feature seems to have been capable of influencing concentration. In the Tolgate deposit (Fig. 5), some of the book mica is concentrated within the wall mica zone in pipe-like shoots that pitch northward parallel to slight rolls of the wall. In the upper E. E. Smith mine, Alexandria, N. H., mica is found in a well defined wall zone in an elongate pegmatite lens zoned parallel to its walls, but the workable concentration is restricted to the part of the zone that lies along the northwest-pitching keel or bottom of the pegmatite lens.

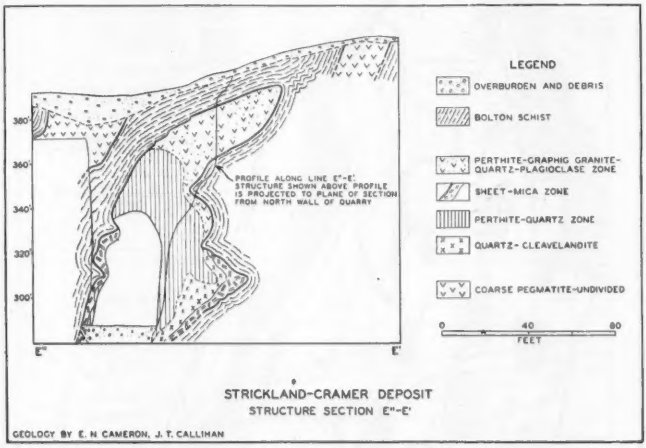

FIG. 7.

In the northern part of the Strickland pegmatite a two-fold structural relationship is shown. This pegmatite (Figs. 6, 7, and 8) is a lens which strikes roughly north-south and dips west. The southern part has been mined in the Strickland quarry, the northern part underground in the Cramer mine. The upper edge of the lens is somewhat uneven, but in general it pitches northward. The upper part contains no sheet-mica zone. In the north end of the Strickland quarry the hanging-wall part of the wall mica zone begins at altitudes ranging from 335 feet (Fig. 7) to about 345 feet. Beginning in the south end of the Cramer workings, the upper edge of the zone pitches irregularly northward, roughly parallel to the upper edge of the pegmatite, so that it intersects the north end of the workings at elevation 260 feet. This is one relationship. The second is that the mica zone is richest in an irregular belt or shoot that lies just inside (down dip from) the upper edge of the mica zone. This is shown in the Cramer workings by plotting the thickness of the zone at

various points on a plan of the workings (Fig. 8). Yield per ton of rock mined from the shoot has been twice to three times the yield from other parts of the zone.

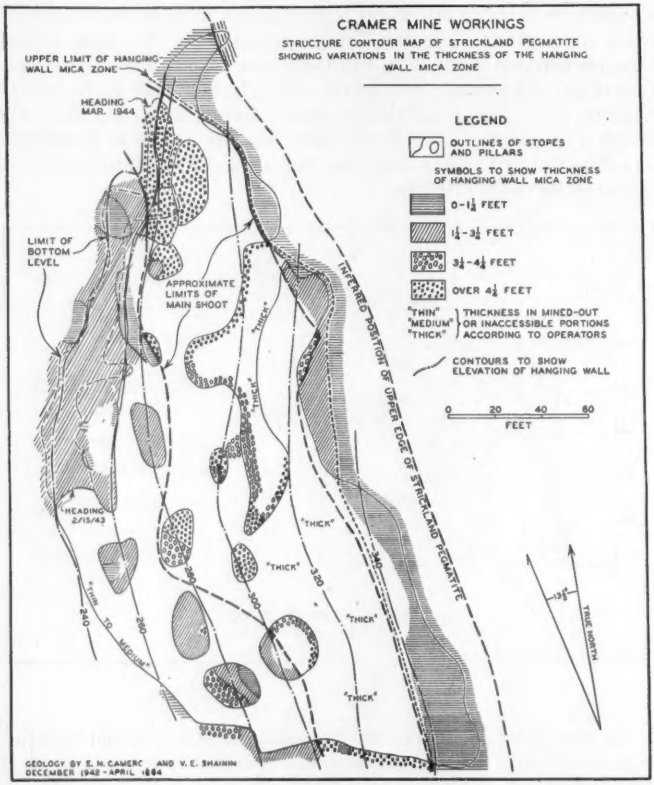
CRAMER MINE WORKINGS
STRUCTURE CONTOUR MAP OF STRICKLAND PEGMATITE SHOWING VARIATIONS IN THE THICKNESS OF THE HANGING WALL MICA ZONE
LEGEND
OUTLINES OF STOPES AND PILLARS
SYMBOLS TO SHOW THICKNESS OF HANGING WALL MICA ZONE
0-1½ FEET
1½-3½ FEET
3½-4½ FEET
OVER 4½ FEET
"THIN" "MEDIUM" "THICK" THICKNESS IN MINED-OUT OR INACCESSIBLE PORTIONS ACCORDING TO OPERATORS
CONTOURS TO SHOW ELEVATION OF HANGING WALL
0 20 40 60
FEET
UPPER LIMIT OF HANGING WALL MICA ZONE
HEADING MAR. 1944
LIMIT OF BOTTOM LEVEL
APPROXIMATE LIMITS OF MAIN SHOOT
INFERRED POSITION OF UPPER EDGE OF STRICKLAND PEGMATITE
HEADING 2/15/43
"THICK"
"THIN TO MEDIUM"
220
260
280
300
320
340
TRUE NORTH
GEOLOGY BY E. N. CAMERC AND V. E. SHAININ
DECEMBER 1942 - APRIL 1944

FIG. 8.

In the Blister mine (Fig. 9), a rich southeastward-pitching shoot has been found within a mica zone along the hanging wall. The direction of pitch of the shoot is roughly parallel to the trend of minor rolls and crenulations in the overlying schist, but development has not yet shown the broader cause of the localization.

Intermediate-zone Deposits.

Certain pegmatites contain mica deposits in zones lying between the wall zone and the core. From their position within the pegmatite body these zones may be termed "intermediate zones" and the deposits within them "inter-

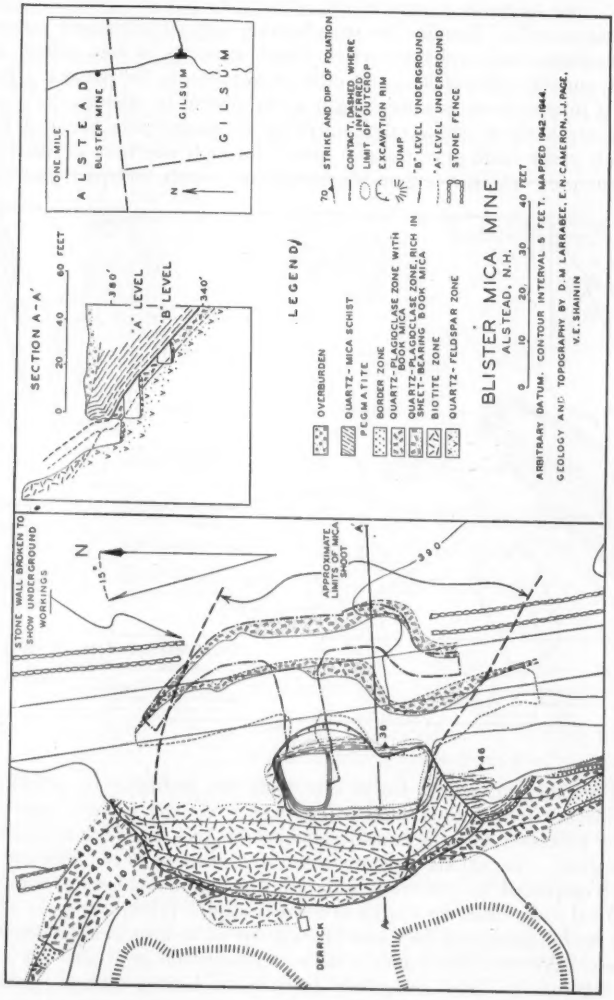
BLISTER MICA MINE
ALSTEAD, N.H.
0 10 20 30 40 FEET
ARBITRARY DATUM. CONTOUR INTERVAL 5 FEET. MAPPED 1942-1944.
GEOLOGY AND TOPOGRAPHY BY D.M. LARRABEE, E.N. CAMERON, J.J. PAGE, V.E. SHAININ
LEGEND
OVERBURDEN
QUARTZ-MICA SCHIST
PEGMATITE
BORDER ZONE
QUARTZ-PLAGIOCLASE ZONE WITH BOOK MICA
QUARTZ-PLAGIOCLASE ZONE, RICH IN SHEET-BEARING BOOK MICA
BIOTITE ZONE
QUARTZ-FELDSPAR ZONE
STRIKE AND DIP OF FOLIATION
CONTACT, DASHED WHERE INFERRED
LIMIT OF OUTCROP
EXCAVATION RIM
DUMP
"B" LEVEL UNDERGROUND
"A" LEVEL UNDERGROUND
STONE FENCE
SECTION A-A'
0 20 40 60 FEET
380'
"A" LEVEL
"B" LEVEL
340'
ONE MILE
ALSTEAD
BLISTER MINE
GILSUM
GILSUM
N
STONE WALL BROKEN TO SHOW UNDERGROUND WORKINGS
N
15°
APPROXIMATE LIMITS OF MICA BODY
390
380
DERRICK

FIG. 9.

mediate-zone deposits." The commonest type of intermediate-zone deposit in New England is the core-margin deposit. In this, mica is concentrated in a narrow zone marginal to and partly or completely enveloping the core of the pegmatite body. Usually the mica-bearing zone is composed essentially of quartz, plagioclase, and muscovite. Small amounts of tourmaline, beryl, columbite-tantalite, phosphates, and other minerals may be present. Potash feldspar is present in some core-margin zones, absent in others.

Cores are likely to show much variation in composition along strike or dip. They range from pure massive quartz through mixtures of quartz and feldspar to pure feldspar, either plagioclase or potash feldspar, plus minor

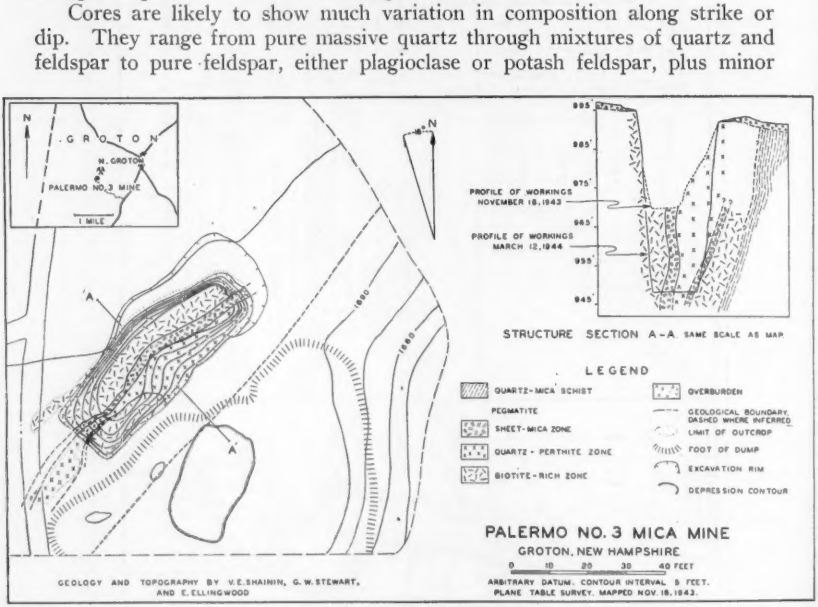

FIG. 10.

amounts of other minerals. Cores commonly are lenticular or pipelike, but their walls are frequently irregular. Where irregularities are pronounced, it may be necessary to mine considerable barren rock in order to follow the marginal zone. Variations in composition or thickness of the core are commonly accompanied by fluctuations in thickness and book-mica content of the marginal zone, either on a large or a small scale. Where the scale is large, virtually barren parts may be found of such size as to lead to abandonment of operations. Where a sheet-mica zone is developed on both sides of a core, as is usual, the two sides commonly differ in book-mica content, quality of mica, or content of recoverable sheet. Some core-margin deposits contain only "wedge" or "herringbone" mica, and in certain of these beryl is relatively abundant.

The Palermo No. 3 deposit (Fig. 10) is of the core-margin type. The core consists predominantly of quartz and large perthite crystals in varying

proportions, but contains plagioclase and graphic granite in places. It likewise varies in thickness. Changes in composition are accompanied by marked variations in mica content and thickness of the accompanying sheet-mica zone. The mica zone, particularly on the southeast side of the core, pinches out entirely in some places. The presence of a biotitic zone immediately outside the mica zone has been of great assistance in tracing the core margins.

The location of the core of a pegmatite is frequently indicated by a bulge in the mass. The innermost zones, the core included, are often restricted to

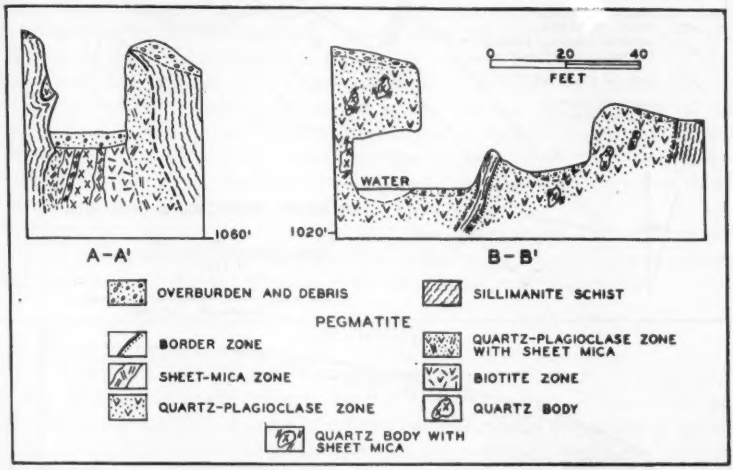

FIG. 11. Structure sections of Keyes No. 1 mine (A-A') and Keyes No. 2 mine (B-B'), Orange, N. H. E. N. Cameron and J. Chivers, September, 1943.

this thickened part. This is strikingly illustrated in the United mine (Fig. 12). Variations in thickness of the pegmatite are indicated on the plan by use of isopachs. The central quartz lens or core is restricted to the thickest part. This pegmatite is a complex deposit, for it has a wall mica zone in addition to the core-margin zone. The two zones are distinct except where the core closely approaches the walls.

The core of the pegmatite in the upper E. E. Smith mine, Alexandria, N. H., and associated intermediate zones also occur in the widest part of the pegmatite. The same relationship, though less clearly defined, is found at the Fitzgibbon mine, Alstead, N. H., and at the Palermo No. 2 mine, Groton, N. H. In the Victory-Gilsum pegmatite the feldspar-rich core, though present in other parts, attains its greatest development in a large bulge exposed in the Victory mine (Fig. 16).

In some pegmatites, intermediate zones are incompletely developed. A given zone may be present only along the crest, or along the crest and sides, of a core. A mica zone that in part of the pegmatite lies immediately ad-

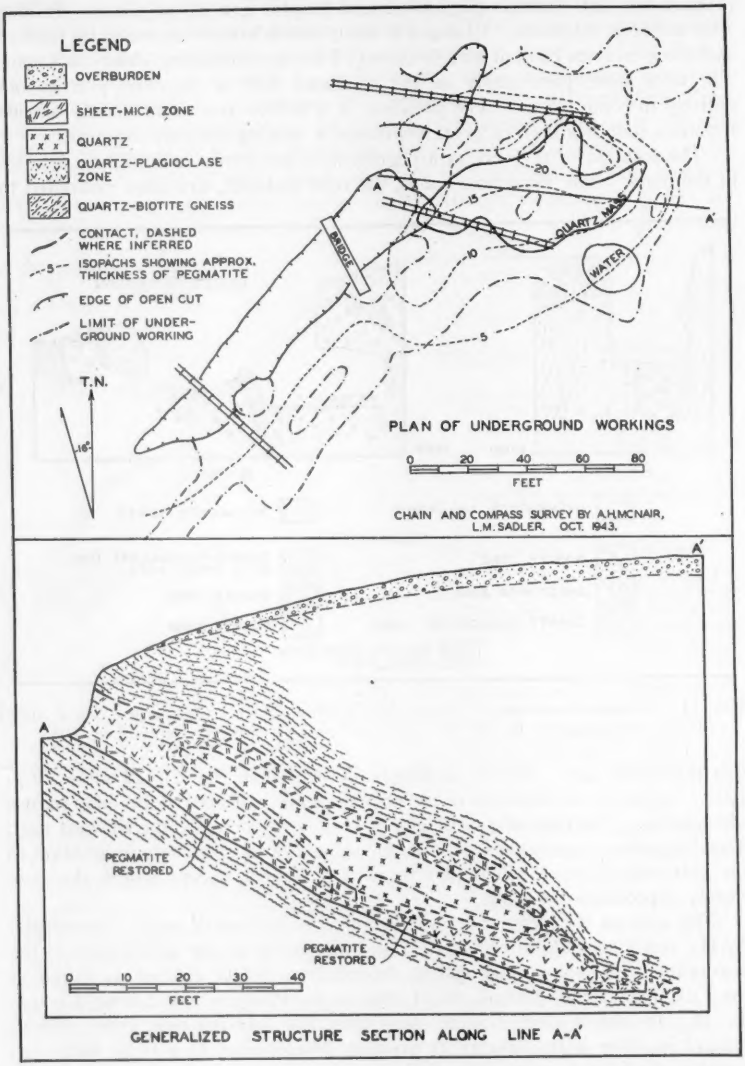

FIG. 12. Isopach map and structure section of the pegmatite at the United Mine, Grafton, N. H.

jacent to the core and appears to be a core-margin deposit, may elsewhere be separated from the core by one or more incomplete zones. This type of intermediate-zone deposit will have a position within the pegmatite that is related partly to the core margin, partly to the outer margin of the intervening zone or group of zones. The Keyes No. 1 deposit (Fig. 11, section AA′) appears to be an example of this type. Along the line of section AA′ the mica zone is marginal to the quartz core, but northward the zone lies along the margins of a body of albitized perthite, beneath which the quartz core appears to plunge. The albitized perthite body is an incomplete zone developed only along the crest of the core. It is noteworthy that the part of the mica zone in contact with quartz was richer in mica than the part in contact with the perthite zone. This pegmatite is a complex deposit, for sheet mica has also been found in a zone along the walls, in places in minable concentration.

A zone rich in wedge mica in the central part of the pegmatite of the upper E. E. Smith mine is similarly related to a northward-plunging quartz core and an incompletely developed quartz-perthite-graphic granite zone overlying the core. Here, however, the feldspathic zone extends part way down the sides of the core between it and the wedge mica zone.

From such occurrences it is clear that unless a pegmatite is well exposed in three dimensions, it may be impossible to determine whether or not a given intermediate-zone deposit within it is actually a core-margin deposit.

Pod Deposits.

Pod deposits of mica are extremely common, particularly in large pegmatite sheets, dikes, and lenses. In this type sheet mica is commonly restricted to the margins of coarse-textured bodies, usually composed of quartz or of quartz and microcline-perthite, which are scattered irregularly through finer-grained pegmatite. The mica books are commonly intergrown with coarse plagioclase and quartz. The pods are typically small and sparsely distributed. The overall content of book mica in a pod-bearing pegmatite is therefore usually small, though around the pods themselves the content may be fairly large. The Keyes No. 2 mine (Fig. 11, section BB′) shows deposits of this type. The Standard mine, Orange, N. H., and the Ashley mine, Rumney, N. H., show other examples.

Though present in many pegmatites, pod deposits have not been important sources of sheet mica, owing to the limited size and sparse distribution of the individual pods within a pegmatite.

Fracture-controlled Deposits.

Many of the same pegmatites that contain pod deposits contain fracture-controlled deposits also. These are thin tabular bodies composed essentially of coarse quartz, perthite, plagioclase, and book mica that appear to follow fractures cutting finer-grained pegmatite. Fracture-controlled deposits range from one-half foot to 8 feet in thickness and from 20 to several hundred feet in length. Most are small and thin and cannot be traced along the strike for

more than 100 feet. The Saunders mine (Fig. 13) illustrates this type of deposit. Fracture-controlled deposits rarely sustain economic mining operations, and records of production from them are therefore few.

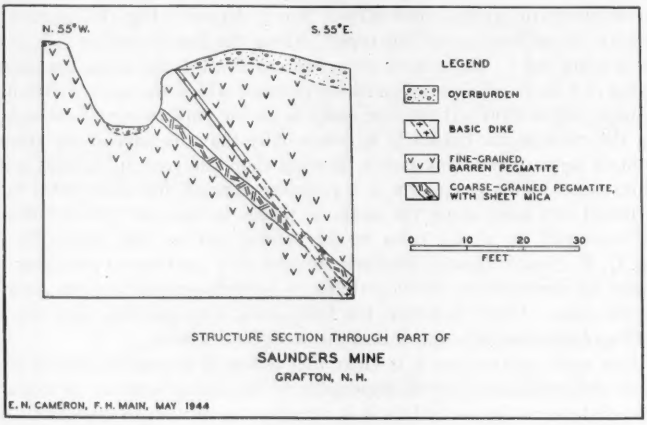

FIG. 13.

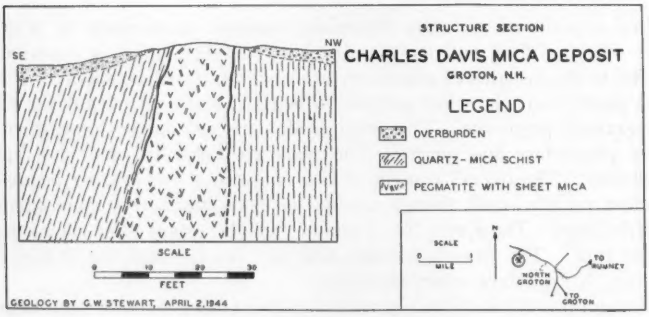

FIG. 14.

Disseminated Deposits.

Disseminated deposits are those in which mica books are scattered without discernible system through the full width of a pegmatite. Usually they are dikes, sheets, or lenses less than 25 feet thick, and they may be as little as 3 feet thick. The Keyes No. 3 and No. 4 mines, Orange, N. H., and the Charles Davis mine (Fig. 14) are examples. At the Rice mine, the principal production was obtained from a deposit of this type worked in the narrow main open cut (Fig. 15, section BB′). The thicker dike shown in section AA′ is

also a disseminated deposit but is much leaner and has yielded little mica. Disseminated deposits are coarse mixtures of quartz, plagioclase, potash feldspar, and book muscovite in varying proportions, with tourmaline, garnet, beryl, and other minerals as minor constituents. In small portions of such

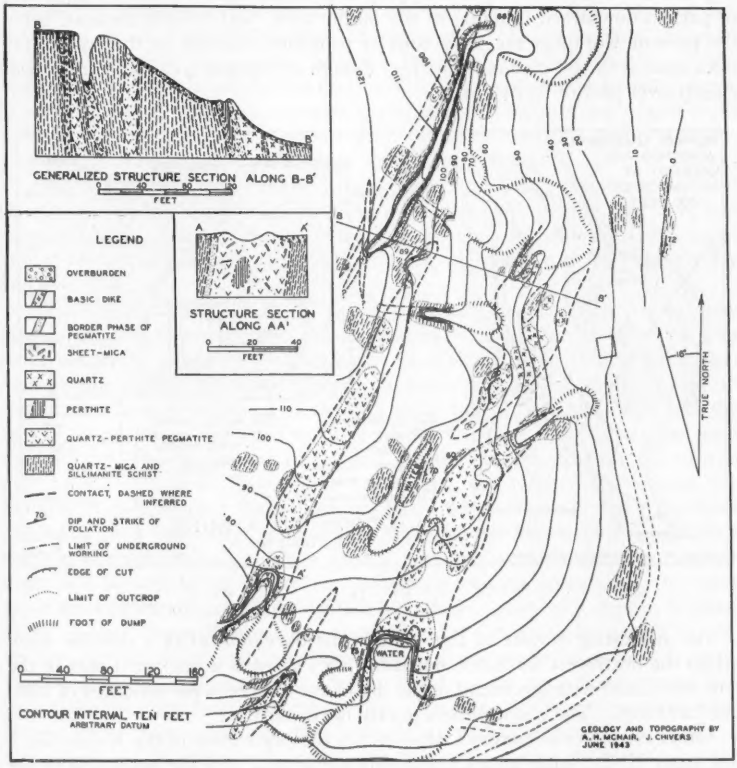

FIG. 15. Map and structure sections of Rice mica pegmatites, Groton, N. H.

deposits the mica may show a tendency to be concentrated along the walls or in the vicinity of quartz-rich areas, but clearly defined, persistent shoots are lacking.

Complex Deposits.

Complex deposits are pegmatites that contain two or more types of sheet-mica deposits. They are not an independent type, and for practical purposes they must be analyzed in terms of component basic types. The Victory mine pegmatite is one example (Fig. 16). This pegmatite contains a wall-zone

deposit along its northwest contact. Another sheet-mica deposit is being mined near the southeast wall. At the present level of the workings the mica of the second deposit is concentrated along the margin of the perthite-rich core of the pegmatite and is separated from the wall by plagioclase-rich biotite pegmatite. The core margin is dipping less steeply than the schist wall, owing in part to downward thinning of the biotite zone, and a short distance below the present workings the mica zone is probably adjacent to the wall. The mica zone is of the core-margin type, though it happens to approach the wall closely over part of its extent.

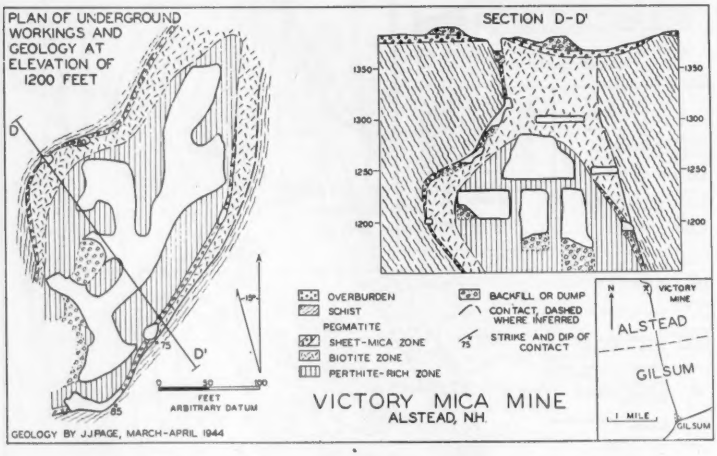

FIG. 16.

An interesting feature of this mine is the development of a definite shoot within the northwest wall-zone deposit. This shoot is a thickened part of the zone associated with a reversal of the dip of the wall between altitudes of 1240 and 1330 feet. The shoot pitches gently northward.

Other examples of complex deposits are the pegmatites in the Keyes No. 1 and upper E. E. Smith mines, previously mentioned, and the pegmatite in the Atwood mine. The Strickland-Cramer deposit also belongs in this class for, though the major production of this pegmatite has come from the wall-zone deposit, irregular bodies of quartz and cleavelandite rich in book mica have been found in places in the central part of the pegmatite, particularly in the Cramer mine.

Special Types.

There are a few sheet mica-bearing pegmatites among those studied thus far that belong to none of the types described above. The most interesting of these is the Nancy No. 1 deposit, Groton, N. H. Here, steeply-dipping mica schist underlies a gently-dipping pegmatite. The schist has been im-

pregnated with pegmatitic material, and in places sheet-bearing muscovite books sufficiently concentrated to be mined have been formed in it.

COMPARISON OF TYPES.

General Remarks. The areas of crystalline rock in New England are known to contain many thousands of pegmatites. Those studied in detail in connection with the present program form only a small fraction of the whole, and are mostly pegmatites that have been prospected or actually mined for mica or beryl. The comparisons given below, therefore, are drawn from a selected group, but there is good reason to believe that this group is representative of New England sheet-mica bearing pegmatites.

Relative Abundance. Of the various types thus far recognized, pod and fracture-controlled deposits appear to be most abundant, though they have few representatives among operating mines. Wall-zone deposits are fairly numerous. Intermediate-zone and disseminated deposits are less frequently found.

Productivity. Table I shows production data for mica deposits in New Hampshire and Connecticut based on records available for 1943. The data cover nearly all productive mines and a number of deposits that have been merely prospected. Data for deposits in Maine are too incomplete to be included, but enough is known of them to show that they would not affect the figures appreciably. Of the five basic types, wall-zone deposits are the most productive. This is due in part to their greater average richness, but also in part to other factors. These deposits on the average are larger and less variable in mica content than other deposits. They present simpler problems of mining than most intermediate-zone deposits, the only group approaching them in average richness. They usually lend themselves readily to development and have a better record for sustaining mining operations. In other types marked variation in mica content in different parts of a deposit is likely to be found. Some intermediate-zone deposits, for example, are fairly extensive, but mica distribution within them is likely to be sporadic. In core-margin deposits, irregularities of the cores and variations in their composition may make the mica zones difficult to trace, or may necessitate removal of much barren rock. Operations on such deposits are usually difficult to maintain.

In pod and fracture-controlled types, the small size of the shoots is commonly the chief drawback. Usually large quantities of intervening barren rock must be moved if appreciable production is to be attained. The cost is commonly prohibitive, and most mining ventures on such deposits have been short-lived. A further drawback is that mica content, quality, and yield of strategic sheet are often found to vary from pod to pod within a given pegmatite.

Few disseminated deposits have proved capable of sustaining commercial operations on a substantial scale. Though mica is scattered within them without discernible system, production records indicate that broad variations in mica content occur. Consistently productive deposits of this type are rare in New England. If the deposits are of sufficient size and of favorable attitude

TABLE 1.

PRODUCTIVITY OF NEW HAMPSHIRE AND CONNECTICUT MICA DEPOSITS
1943

TYPE OF DEPOSIT	NO. OF MINES REPRESENTED	AVERAGE MINE-RUN PROD. PER MO. OF OPERATION—TONS	AV. MINE-RUN PROD. PER MINE—TONS	RATIO OF ROCK MINED TO MINE-RUN MICA PRODUCED		SHEET RECOVERY FROM MINE-RUN	APPROX. % OF TOTAL N.H. AND CONN. SALES OF STRATEGIC MICA TO COLONIAL MICA CORP.	
				AVERAGE	RANGE		SHEET	PUNCH
WALL-ZONE	30	7.16	62.6	39:1	8:1 TO 90:1	1.1 TO 6.8%	72.7%	89.2%
INTERMEDIATE-ZONE	6	6.5	46.8	55:1	12:1 TO 75:1	1.7 TO 6.0%	10.8%	4.5%
POD AND FRACTURE-CONTROLLED	9	2.76	9.3	140:1	70:1 TO 290:1	1.1 TO 3.8%	.7%	.34%
DISSEMINATED	13	3.38	9.9	75:1	40:1 TO 97:1	2.3 TO 11.1%	7.8%	5.9%
COMPLEX AND SPECIAL	5	6.0	27.4	—	36:1 TO 63:1	3.9 TO 6.1%	.8.0%	.06%

NOTES: COMPLEX DEPOSITS—UNDER THIS HEADING ARE INCLUDED ONLY COMPLEX DEPOSITS FOR WHICH SEPARATE PRODUCTION RECORDS ARE NOT AVAILABLE FOR THE INDIVIDUAL MICA CONCENTRATIONS.
SHEET RECOVERY—SHEET INCLUDES SMALL SHEET. DATA DO NOT COVER MINES WHICH SELL PUNCH.
PERCENTAGES OF TOTAL SALES—BASED ON DATA SUPPLIED BY COLONIAL MICA CORPORATION.

and topographic position, however, they are amenable to low-cost mining on an extensive scale.

In comparing yields of various types of deposits (Table I) many factors must be considered, but from the practical standpoint three are especially important; namely, richness expressed in terms of the ratio of mine-run mica produced to rock mined, yield of strategic sheet per ton of mine-run, and quality of mica.

On the average, wall-zone deposits are richer in mica than other types, with intermediate-zone deposits next. No one type, however, is markedly superior in yield of strategic sheet per ton of mine-run. This is not altogether surprising. For any given mine this figure is strongly influenced by factors that have no connection with the original development of the pegmatite; namely, later deformation of the deposit, variations in mining technique, and efficiency of the rifting and trimming processes. Any of these may markedly affect the ultimate recovery of sheet. A further complication is that in some pegmatites broad variations in strategic sheet yield, even of single ore bodies, are shown by production records. In some mines these variations can be correlated with faulting, shearing, or other geologic features, but in others the causes are obscure.

Correlation of quality variations with types of deposits is not yet feasible, except insofar as quality is implied in strategic sheet yield. Qualitative observations, however, suggest that this matter is complicated by regional variations. Mica from certain districts is in general superior in quality to that from others, regardless of types of deposits involved. Furthermore, within individual geographic areas certain variations in quality appear to correspond to differences in geologic occurrence. In the Middletown district of Connecticut, for instance, strategic sheet mica is being obtained only from pegmatites in the Bolton schist. Mica deposits occur in other rock formations such as the Monson (Glastonbury) granodiorite, but none have been sufficiently productive of sheet of strategic quality to warrant mining, even under wartime conditions.

APPLICATIONS TO PROSPECTING AND MINING.

Recognition of the Type of Deposit. Production records indicate that in evaluating mica prospects it is important to recognize the type of deposit, as on this basis a forecast of the productivity can be made within certain limits. Recognition of the type likewise affords a basis for mining and development, which of course must be governed primarily by the manner in which the mica is distributed. In many deposits the relation of mica distribution to structural features has an important bearing on efficient exploitation, and such relations are worthy of the same attention that is given them in other kinds of mineral deposits.

Recognition of Productive Pegmatites. Studies so far have shown that no sharp distinction can be made between barren and productive pegmatites. Mica-bearing zones, even wall-zones, are nowhere co-extensive with a pegmatite body, and even in disseminated deposits variations in mica content

occur. The pegmatite that is virtually barren for much of its length may contain a well developed mica zone with a workable shoot in the remaining portion. These considerations greatly complicate the problem of prospecting; not only the right pegmatite but the right part of it must be found. Generally the best indication of a potentially productive pegmatite is the presence of a pronounced zonal structure. Pegmatites that show evidence of such internal arrangement deserve particular attention from prospectors, as they may contain concentrations of the intermediate-zone or wall-zone types that have been the principal sources of sheet mica in New England in the past. In addition, accompanying zones may contain concentrations of other commercial minerals, especially feldspar. The prospector should recognize in advance, however, that pegmatites containing workable wall-zone or intermediate-zone shoots are exceptional occurrences and therefore constitute a very small proportion of known pegmatites.

Mineralogical and Structural Indications. The presence of plagioclase-rich zones along the walls of a pegmatite, though by no means infallible, is the best indication yet known of the possible presence of wall-zone deposits. The presence of much potash feldspar or biotite, on the other hand, is an unfavorable indication. If plagioclase-rich zones are found, prospecting of easily accessible parts of the zones is usually warranted. If this is done, however, the prospector must be aware that a small part of such a zone may not be a guide to the average productivity. In some wall zones there is a distinct concentration of mica into shoots separated by leaner portions. Failure to explore a wall-zone deposit of this kind in advance of operations leads either to over-optimism or discouragement, depending on whether the leaner or richer parts of the zone are mined first. In addition, opportunities for selective mining are sometimes overlooked. The frequent occurrence of cores in bulges in a pegmatite mass is a clue to the location of core-margin deposits. The prospector must be aware of the variations that must be expected in the composition and shape of the cores, as these are likely to be accompanied by changes in mica content of the core-margin zones. In general, marginal zones are more likely to be productive along quartz-rich cores or parts of cores than along feldspar-rich cores, but there are several exceptions. In view of these variations, it is desirable to uncover the core margins over as great a length as possible and to sample the marginal zones at frequent intervals before deciding on the scale of operations. A study of the core itself and of the composition of adjacent zones will assist materially in tracing the mica zones, particularly in places where these become lean and difficult to follow on the basis of mica content.

Vertical Variations in Mica Content and Quality. Much effort and money have been expended in New England in prospecting pegmatites that are barren or virtually barren in outcrop, in the vague hope that these pegmatites would contain more mica at depth. It is scarcely surprising that scant success has attended such prospecting, which is based on misunderstanding of the origin of pegmatites. The fact that mica distribution and content were determined at the time of pegmatite formation, not by later processes, has not been generally recognized in the industry.

In some cases, however, hope of a downward increase in mica content is justified by structural evidence. If mapping and study of a deposit indicate, for example, that a potentially productive zone lies below the surface, then downward increase in mica content becomes a reasonable possibility.

The widespread belief that mica quality always improves with depth is equally fallacious. In pegmatite outcrops, the mica books are often soft, water-soaked, and split by frost along cleavages. Only rarely do these effects extend more than a few feet downward in New England pegmatites. The same is true of organic stains. Rust stain likewise extends normally only to shallow depths. If, however, a pegmatite is badly fractured, or if either pegmatite or wall rock contains much pyrite, rust stain may extend 50 feet or more below the surface as a result of weathering and ground water activity. Far more serious than surficial defects in their bearing on content of strategic sheet, however, are "mineral stains" and mineral inclusions, and the structural defects known as "reeving," "ruling," "A-structure," "cross-cracking," "wedging," "crumpling," "waviness," "herringbone," and the like. These defects developed at the time of pegmatite formation or as a result of later deformation. Except in the very few places where erosion has been guided by the same structural features that have affected the mica, such as faults, the degree to which the defects listed are developed will of course have no relation to surface topography or to depth below the surface. As might be expected, production records show plainly that mica quality is as likely to become poorer downward as to improve.

Exploration and Development of Mica Deposits. Mica mining ventures are usually small, and as operations are frequently undertaken with little capital, exploration and advance development are customarily kept at a minimum or not done at all. Although there are sometimes sound reasons for this practice, particularly under conditions of high price-subsidy and short-term guarantees, the result is that opportunities for efficient operation or for expansion of the scale of mining are at times neglected in the haste to get into production. In the long run this procedure is wasteful, and in some instances it is a serious deterrent to production, for it means that only the promising outcrops are likely to be explored, that even in these a system of "robbing" the richer parts is likely to be practised, and that mining operations are frequently started without proper appreciation of the nature of the deposit. Without some well planned development work, too, only a very limited number of working faces can be opened on a given deposit at one time. This in turn is one of the reasons why certain deposits capable of sustaining large and continuous production if systematically developed have operated on a small scale even under the urgency of war-time conditions.

U. S. GEOLOGICAL SURVEY,
WASHINGTON, D. C.,
Feb. 15, 1945.

THE CHICOTE TUNGSTEN DEPOSIT, BOLIVIA.

FEDERICO AHLFELD.

ABSTRACT.

The Chicote district, situated in the eastern part of the Central Bolivian Andes 65 km. NNE of Oruro, is one of the larger tungsten producers of the country. The deposit is of the cryptobatholitic type. There are narrow, mineralized fissures in Devonian shales above an unexposed intrusive. The shales of the roof are altered extensively to a quartz-tourmaline rock. Within an area of approximately 4 square kilometers, 72 veins and veinlets are known. The mineralization is hypothermal. The vein structure is massive to vuggy. Quartz is the principal gangue mineral. The only tungsten mineral is wolframite associated with large quantities of pyrrhotite. The vein zone has a vertical range of 1300 meters without any pronounced change in the mineral content. The district is composed of a fringe zone of tin veins surrounding a central core of wolframite veins.

Within recent geologic times large masses of the vein zone slid into the Ayopaya valley forming a brecciated talus containing a large tonnage of low grade wolframite ore of economic value.

CONTENTS.

	PAGE
Introduction	394
Morphology	394
General geology	396
The ore deposits	398
Wolframite veins	398
Cassiterite veins	403
"Llamperas"	404
Summary of the origin of the deposits	406

INTRODUCTION.

About 75 per cent of the Bolivian tungsten production comes from deposits of normal hypothermal veins. Investigations by the author of nearly every tungsten deposit of Bolivia[1] showed that the wolframite deposits belong to a well defined zone, situated nearer the central batholitic core than the principal tin zone. The most complete development of the tungsten zone was observed in deposits of the cryptobatholitic type. Of these the Chicote deposit is one of the richest and most interesting.

MORPHOLOGY.

The Chicote district belongs to the northern part of the Bolivian tin-tungsten zone. It is situated at 17° 28′ south latitude; 66° 50′ west longitude; 65 km. north-northeast of Oruro, on the eastern slope of the Central Andes.

[1] Zoning in the Bolivian tin belt. Econ. Geol. 36: 569–588, 1941. Los yacimientos de wolfram de Bolivia. La Paz, 1942.

It is on the edge of the Amazon basin and the Ayopaya river, a tributary of the Beni, forms the boundary of the Inquisivi province of the department of La Paz, and the Ayopaya province of the department of Cochabamba. This river cuts the Chicote mountain placing Chicote Grande in the Inquisivi province and Chicote Chico in Ayopaya province (Fig. 1).

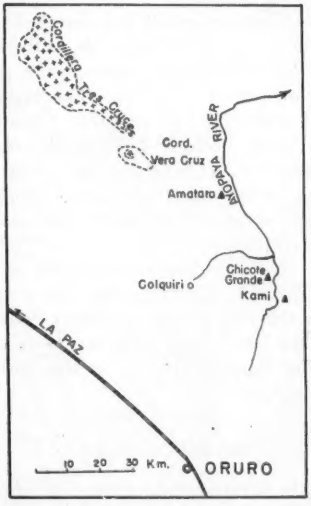

FIG. 1. Location of the Chicote district.

The Chicote mountain is situated southeast of the Cordillera of northern Bolivia with its deeply eroded granitic cores. In this area the Cordillera widens and due to peneplanation the average elevation diminishes. Igneous rocks have not been exposed by erosion.

The lightly dissected Pliocene peneplain has an average elevation of 4,400 m. on the continental divide about 20 km. west of Chicote. It appears as a wide plain with traces of former glaciation. It slopes eastward and has been extensively dissected within recent times by the cañon-like valley of the Ayopaya river and its tributaries. Here the average elevation of the peneplain is approximately 4,200 m. Nearer the Ayopaya valley there are three isolated peaks which stand out from the surrounding peneplain by virtue of their extremely rugged topography (Fig. 1). The Serrania de Amutara (4,600 m.), to the northeast, forms a small sharp ridge with traces of glaciation; Chicote (4,100 m.), 30 km. south-southeast of Amutara, and Kami (4,280 m.), 7 km. south-southeast of the latter, are both smaller. Chicote and Kami represent erosional remnants of the Pliocene peneplain. The Chicote mountain extends 4 km. in a northwest-southeast direction. The larger portion, Chicote Grande, is located on the west side of the Ayopaya river.

The rugged ridge is isolated on three sides with only a small narrow ridge connecting it to the peneplain to the west. The Ayopaya valley borders it on the east and north and the valley of the Lapiani river on the south. The Ayopaya river cuts a deep cañon in the Chicote massif which in its narrowest part is only 8 m. wide. This has formed a small peak, Chicote Chico (3,300 m.), on the east side of the cañon.

As mentioned above Chicote Grande is connected to the peneplain upland by a narrow ridge. The excessive relief is due to the deep cut valleys.

The relief from the top of Chicote Grande to the Ayopaya valley is 1,600 m. over a horizontal distance of 1,500 m. The inclination of the slope of Chicote Grande on its southern side opposite Chicote Chico reaches 65°. This has given rise to great climatic differences over relatively small distances. The upper slopes of Chicote Grande are covered by "Ichu" grass and belong to the cold Puna zone, while the lowest slopes along the Ayopaya valley are covered by dry scrub. The valley, with an elevation of 2,500 m., has a subtropical warm climate.

The Ayopaya valley has a gradient of 4 degrees in the upper reaches and this flattens to 2 to 3 degrees further north. As a consequence of the decrease of rainfall during the past decade the valley floor is choked with gravel and boulders. Within the last 5 years there has been a change in elevation of the valley floor near the Ingenio Hector on the northeast side of Chicote Grande of approximately 9 m.

GENERAL GEOLOGY.

The country rock of the Chicote district consists of a thick series of sandy shales and sandstones belonging, according to fossil evidence found at Kami, to the Eodevonian. Thin beds of sandy shales and bluish slate are intercalated with thick beds of hard quartzitic sandstones. The general strike of the sedimentary series is N 45° W, corresponding to the general strike of the Andes in this latitude. The sediments are moderately folded, forming broad anticlines and synclines. Overthrust faults with a steep southwestern inclination are common. The shales are, in part, somewhat sericitic. Nearer the Chicote massif they pass gradually into thicker micaceous shales that change in the central zone of Chicote to light grey hornfels and silicified shales without traces of the original bedding. Thin sections show that the dark color of many of these rocks is due to inclusions of small needles of tourmaline. Lighter and darker portions give rise to the common banded appearance of the more massive beds. The central zone of tourmalinized and silicified rocks covers approximately 4 square kilometers (Fig. 2). In this zone the sediments are strongly folded and compressed. They form a narrow anticline-like structure, the axis of which strikes N 30° W, crossing the top of both Chicote Grande and Chico (Fig. 2). The sediments dip steeply on both limbs of this structure. Near the axis of the anticline dips of 70° were measured. On the western slopes of Chicote Grande, near the boundary of the soft shales of the periphery and the metamorphic rocks of the core, there are a number of strong faults several of which are well exposed in the Lapiani

mine. These faults are of a more recent formation than the wolframite and cassiterite mineralization and, in consequence, are barren.

In the Amutara, Chicote, and Kami districts, all of which show strong analogies in their geological structure, neither plutonics, pegmatites or eruptive dikes have been exposed.

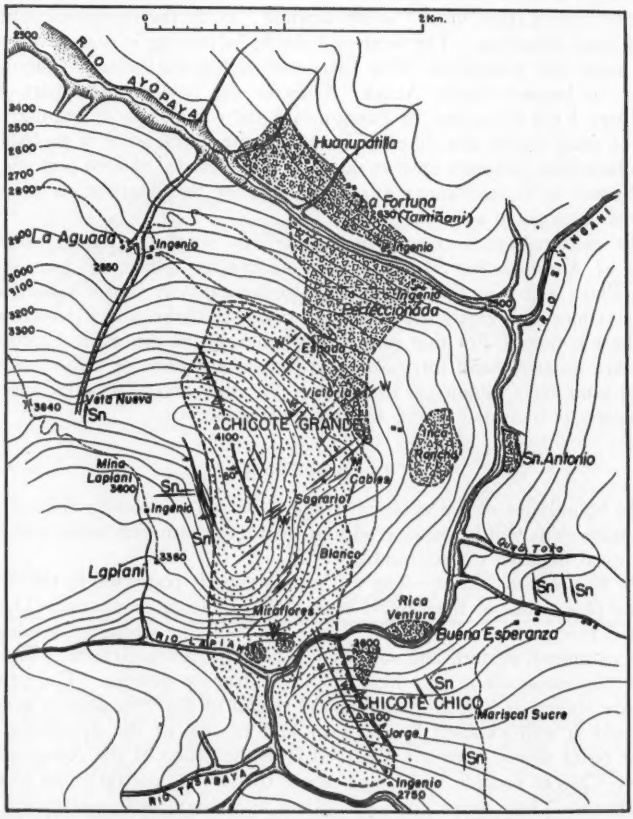

FIG. 2. Geologic map of the Chicote massif. Metamorphosed shales, dots; wolframite bearing talus landslides, triangles and dots; W, wolframite veins; Sn, cassiterite veins.

The line of these three massifs is a zone of dislocation with a general north-northwest strike which probably has been produced by three separate small hypabyssal intrusions that locally faulted the overlying sediments. In the zones above these intrusives the sediments are intensively altered by ascending magmatic solutions and gases which carried SiO_2 and tourmaline

in large quantities. Only a guess can be made as to the elevations of the crest of the intrusives. It is estimated that the postulated intrusive beneath the Chicote massif lies some 2,000 meters below the present surface.

One of the broad tectonic features of the northern section of the eastern Bolivian Andes, in the Cordillera Real and the Cordillera Tres Cruces (Fig. 1), is a great bend with a granitic core that strikes southeast and continues south to Tres Cruces at 17° south latitude. Here the cordillera splits into two distinct branches. The western branch, increasing in size to the southeast, forms the Cordillera Vera Cruz and continues through Colquiri and Caluyo to beyond Conde Auque. Only in the northwestern part, in the Cordillera Vera Cruz and in Paragui, are there outcrops of granite, in the form of small stocks and dikes. Farther to the southeast it is probable that cryptobatholitic plutonics exist in depth. The presence of such plutonic rocks is indicated by contact-zones (Colquiri) and by the distribution of various deposits of tungsten and tin.

The eastern branch extends to Chambillaya, south of Quime. The Cordillera of Amutara lies 30 km. farther southeast. Since the area between Chambillaya and Amutara is unknown geologically, it is not known if any tectonic connection exists between these two cordilleras, and it would appear that there is none. For that reason it is believed that Amutara, Chicote, and Kami are isolated small intrusions and the eastern limit of a zone of strong folding some forty kilometers in length. No other cryptobatholitic intrusives are known or indicated to the southeast of Kami.

THE ORE DEPOSITS.

The boundaries of the wolframite and tin zones are clearly defined. The wolframite veins will be considered first, then the cassiterite veins, and finally the alluvial deposits of wolframite.

The Wolframite Veins.—The wolframite zone is restricted to the contact-metamorphic rocks of the central core of the Chicote mountain. The general structure is shown in Fig. 2. The veins show the strongest development on the northeast, eastern and southern slopes of Chicote Grande. The summit of this mountain is just west of the wolframite district. The principal veins are shown in Fig. 2. The vertical extent of the vein zone is generally great and is well exposed by the profound erosion of the mountain. The deepest point where veins are observed is in the cañon of the Ayopaya river between Chicote Grande and Chico where two veins outcrop at an elevation of 2,600 m. These veins cross the cañon and carry weak wolframite mineralization. The highest outcrops are found to the southeast of the summit of Chicote Grande at an elevation of 3,900 m. The vertical range of the vein zone, 1,300 m., is the greatest yet observed in Bolivia.

The veins strike in all directions and dip from nearly horizontal to vertical. In general the veins can be placed in one of three strike groups:

1. Veins with a general northwestern trend, dipping about 60° SW, are limited to a zone near the axis of the anticline. They outcrop southeast of the crest of Chicote Grande and on Chicote Chico. The strike and dip of the

veins correspond to those of the wall-rock. These veins are narrow and of little commercial importance.

2. The Rajada vein of the Miraflores section outcrops at an elevation of 2,900 m. on the southern slope of Chicote Grande. It strikes east-west and is flat-dipping.

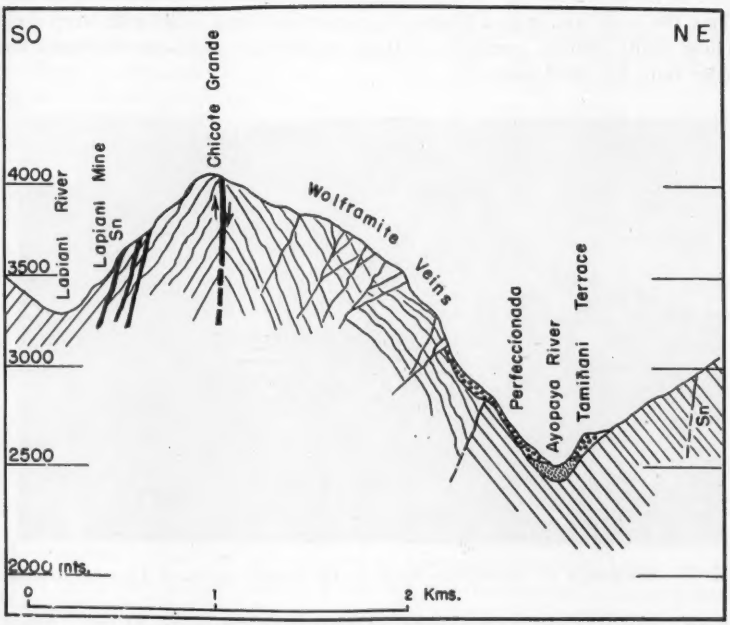

FIG. 3. Schematic cross section of Chicote Grande.

3. The veins of the northeast, east, and southern portions of Chicote Grande have variable strikes and dips. The strikes vary between N 35° E and N 84° E; the dips between 45° and nearly vertical. About 40 rich veins and a host of narrow stringers here form a stockwork of unusual size. The entire extent of this stockwork along the eastern side of Chicote Grande as seen from the eastern side of the Ayopaya valley is shown in Fig. 4.

All are narrow fissure veins without fault contacts and commonly with curving strikes. The horizontal extension varies from a few tens of meters to several hundred meters. In vertical range several veins can be followed, such as the principal vein of the Cables section, for more than 500 m. This vein, striking N 60–84° E, is made up of a series of shattered veinlets, in part dipping steeply NW, in part SE, apparently joining a trunk vein in depth. Near the outcrop, the vein gradually splits up into numerous veinlets and stringers.

In the Victoria and Espada sections and in the northeastern portion of the mountain the veins generally strike N 60° E and dip from 40 to 60° northwest.

Evidence of strong movement along the veins is not observed. They are, however, tension structures. Where the veins cut one another there has been little or no displacement. On the other hand, in the Cables and Victoria sections, the veins are cut by a system of younger east-west faults with steep dips. These faults contain pyrrhotite without wolframite and have displaced the older veins for small distances.

FIG. 4. Stockwork of wolframite veins on the eastern slope of Chicote Grande.

The veins are generally narrow, varying in width up to 40 cm. Along the principal vein of the Cables section there are areas where they attain a width of 1.20 m. but the measured average width of 70 veins is 22 cm.

The grey hornfels forming the wall rock of all the veins has not suffered intense alteration. Idiomorphic arsenopyrite is commonly found in the wall rock up to 5 cm. from the veins, and pyrite and pyrrhotite penetrate the wall rock along small fissures. There are no selvages and the veins are frozen to the wall rock. The vein structure is generally massive and the vein filling is mostly coarse grained. Druses of quartz crystals with wolframite are common. Some of the steeply dipping veins of the Cables section carry open fissures in the upper portions, which are lined with crystals of colorless quartz and wolframite. The walls are commonly covered with crystals of quartz and the center is filled with massive pyrrhotite.

The mineral content of the veins is remarkably uniform. The gangue consists of coarse white quartz with the waxy luster so typical of hypothermal deposits. In the druses and open fissures the quartz is well crystallized,

opaque and white, or transparent. The occurrence in the Cables section of Japanese twins up to 6 cm. along the edge is of mineralogic interest.

Lithium-bearing muscovite is found in the wall rock and associated with the vein quartz, but it is not common. Feldspars have not been observed. Tourmaline occurs in three generations. Its presence in the hornfels wall rock where it is probably of pneumatolytic origin is mentioned above. It also occurs in coarse black crystals along the walls of the Rajada vein of the Miraflores section and in very thin needles in water-clear crystals of quartz.

There is a younger generation of light brown, strongly-pleochroitic tourmaline that covers crystals of wolframite or fills open fractures as matted masses. Late tourmaline in transparent, light yellow needles up to 4 cm. long is found covering siderite crystals in druses.

The following ore-minerals have been observed: wolframite, pyrite, arsenopyrite, pyrrhotite, chalcopyrite, sphalerite, native bismuth, bismuthinite and siderite. The mineralization of Chicote corresponds closely to that of most of the other hypothermal tungsten deposits of Bolivia.

Wolframite, which forms 1 to 20 per cent or more of the vein content, occurs principally in crystal groups and crystalline masses. Such masses or "bolsones" may occupy the entire vein width but generally pinch out rapidly in all directions. Compared to the older vein quartz, wolframite is allotriomorphic, often filling the openings between the quartz crystals. When it occurs in pyrrhotite, a common association, it is always idiomorphic. Individual crystals up to 10 cm. along the edge are not uncommon in pyrrhotite. In the outcrop of a vein in the Victoria section tabular crystals of wolframite weighing up to 20 kg. were found in massive cellular limonite formed through oxidation of pyrrhotite.

In druses and open fissures crystals of wolframite occur perched on crystals of quartz. They are thick tabular or prismatic, commonly highly modified. A crystallographic study of the Chicote wolframite is in progress. This deposit has supplied the most beautiful specimens of wolframite in the world, especially the magnificent druses of quartz crystals covered with large lustrous black crystals. Chemically the mineral is wolframite carrying 16 per cent FeO and 7 per cent MnO.

Cassiterite was not observed in the wolframite veins nor in polished sections of the ores. But since the concentrates of wolframite from the alluvial deposits, which will be dealt with later, always show a small tin content (0.5 to 1.2 per cent), there is no doubt but that some of the veins carry cassiterite and a more extended study of polished sections would reveal its presence. A boulder from the outcrop of a wolframite vein in the Incarancho section contained a druse covered with dark brown twinned crystals of cassiterite.

Pyrite is notably scarce. In places it occurs filling small fissures in the wall rock but it is completely lacking in most of the veins. It is common only in the northwest striking veins near the top of Chicote Grande.

Arsenopyrite, the oldest sulphide mineral, commonly impregnates the wall rock and occurs, together with quartz, in coarse grained masses in the veins. The sharp brillant crystals that occur in vugs on clear quartz crystals belong

to a younger generation. Occasional crystals of arsenopyrite are found enclosed in the quartz crystals.

Pyrrhotite is almost always associated with wolframite. Coarse massive pyrrhotite with idiomorphic wolframite commonly forms the only vein filling. In places the pyrrhotite replaces the wolframite. This replacement starts along the edges and continues inward (Fig. 5).

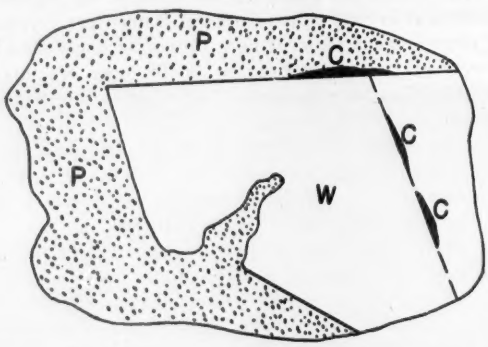

FIG. 5. Pyrrhotite replacing wolframite. Cables section. 0.4 nat. size. P, Pyrrhotite; W, Wolframite; C, Chalcopyrite.

In many veins crystals of quartz normal to the walls form bands along both sides, and pyrrhotite fills the central part. A rough intergrowth of quartz and pyrrhotite is found in many veins. In the Orego vein of the Cables section pyrrhotite shows idiomorphic development. The idiomorphic individuals have a diameter up to 5 cm. In druses are small thick tabular crystals.

Chalcopyrite occurs sparingly in small veinlets in quartz and wolframite (Fig. 5). Dark brown *sphalerite* covered with crystals of siderite was found in a large druse in the Orego vein but this was the only observed occurrence. *Siderite* occurs as the youngest vein mineral. It was noted in lentiform rhombohedrons of great beauty in a druse on the Orego vein.

The age relationships of the various minerals are given in Fig. 6.

The zone of oxidation is poorly developed. Many veins in the lower section of the mountain carry sulphides in their outcrop. Along the eastern side of Chicote Grande the zone of oxidation is parallel to the slope, but nowhere is it more than 20 m. deep. The pyrrhotite at the oxide-sulphide contact is altered to a mass of fine granular pyrite-marcasite that shows a "bird's-eye" structure under the microscope. In the oxide zone the pyrrhotite generally alters to a red-brown cellular limonite. In the Cables section the alteration of pyrrhotite to vivianite was observed within a limited area.

Rarely earthy tungstite coats the wolframite. Crystals of wolframite in the oxide zone in places show a rough corroded surface. Scorodite and jarosite are minerals characteristic of the oxide zone.

It is remarkable that there is so little change in mineralization in depth in spite of the great vertical development of the deposit. The richest wolframite zone is between elevations 3,200 m. and 3,600 m. In the deeper portions of the mountain the veins are quite uniform, but with a much lower content of wolframite. Above 3,600 m. the veins split and become poorer. The highest veins carry pyrite instead of pyrrhotite.

Cassiterite Veins.—The central core of Chicote which carries the wolframite veins is surrounded on all sides by a peripheral tin zone. There are no transitions from wolframite veins to cassiterite veins. The former belong to an older phase of mineralization more closely related to the magma source.[2]

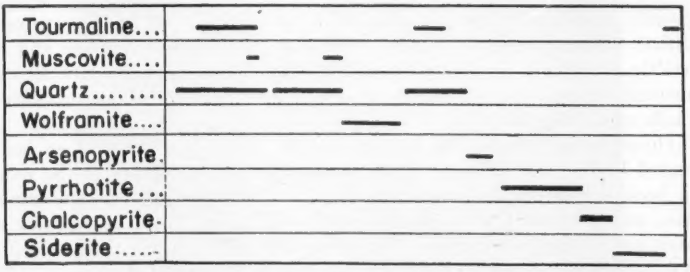

FIG. 6. Sequence of mineral deposition in the wolframite veins of Chicote.

The cassiterite veins show no regularity in either strike or dip and have formed along dislocations in soft micaceous shales. They have well developed clay walls and have been intensely faulted. Cassiterite occurs in shoots of irregular distribution. These veins, characteristically, have little vertical extension. The mineral composition is simple. The gangue is quartz. The cassiterite is fine-grained and shows small twinned crystals under the microscope. Associated minerals are fine granular pyrite and rarely wolframite in small tabular crystals.

The tin veins are found in an almost uninterrupted annular zone around the Chicote massif (Fig. 2). To the west of Chicote Grande, at an elevation of 3,600 m., the Nueva vein outcrops in a gulch opening into the Aguada valley. This vein carries cassiterite as disseminated inclusions in limonite and quartz; the width is 30 cm. The Lapiani mine is located at approximately the same elevation farther to the south on the west slope of Chicote Grande. This has been an important tin producer for many years. The strong outcrop of the vein, exposed for more than 300 m., strikes east-west and dips nearly vertical. To the east it is cut by a series of transverse faults. The vein occupies a heavy and strong fault plane along which there has probably been extensive movement. A soft grey-blue shale forms the wall rock. The vein filling consists of pulverized clayey shale debris impregnated with cassiterite. The cassiterite is very fine grained and of light brown color. 100 m. below the outcrop the mineralization becomes poorer. Fine grained

[2] F. Ahlfeld: Zoning in the Bolivian tin belt. ECON. GEOL. 36: 569–588, 1941.

pyrite accompanies the cassiterite, in places with thin reedy crystals of bismuthinite. Of mineralogical interest are free octahedrons of pyrite and groups of these crystals, up to 15 cm. along the edges, that occur in the fault clay, which has also been impregnated with cassiterite, groups of arsenopyrite crystals, and large lenticular rhombohedrons of siderite.

Numerous other tin veins, some of which occur up to 2 km. from the Chicote massif, are found southwest and south of Lapiani. The Mariscal Sucre and Buena Esperanza mines are situated to the east of Chicote Chico. The veins of these properties carry shoots of fine granular cassiterite with pyrite and quartz. The wall rock is shale.

"Llamperas."—In Bolivia the name "Llamperas" is given to deposits, especially wolframite deposits, formed by landslides which have occurred in relatively recent periods. Typical llamperas are found at Chicote and less perfectly developed in other parts of Bolivia. There are extensive strongly cemented tungsten-bearing talus slides on the northern slope of Chicote Grande containing several millions of tons of low grade wolframite ore.

Through the progressing erosion of the Ayopaya river, whose bed is situated 1,500–1,600 m. below the crest of Chicote, the slopes of the mountain became so steep and high that enormous masses of the metamorphosed shales and hornfels interlaced with wolframite veins broke away from the massif and slid into the cañon. This took place within recent times and present erosion has not carried the floor of the valley to its old elevation. There can be distinguished, through differences in their materials, two large landslides and a series of smaller ones. The first three small landslides, the last composed only of dark shale, covered the bottom of the valley. They are well exposed in the open cast of the Perfeccionada mine and along the northeastern side of Chicote Grande. The fourth was a great landslide which carried down hundreds of millions of cubic meters of rock and filled the entire bottom of the valley forming the terrace of Tamiñani on the eastern side of the Ayopaya river. This terrace is 150 m. above the present river bed. The landslide made a natural dam and formed a lake for at least 1 km. up the valley. Remnants of the terraces of this lake are still visible. A final landslide carried down strongly cemented material which today forms the front of the Huanupatilla terrace and has produced an escarpment on the eastern side of the Ayopaya river. Fig. 7 shows in the left foreground the open cut of the Perfeccionada placer; on the right beyond the Ayopaya river, the nearly worked out terrace of Tamiñani; and, in the background, the great and almost intact terrace of Huanupatilla.

Smaller landslides are those of Incarancho. There is a terrace at an elevation of 3,000 m. below the stockwork of wolframite veins of the Cables section. On the other side of the Ayopaya cañon there is the small terrace of San Antonio.

These llamperas consist of a light-yellow to ochre-yellow breccia, the color being due to limonite. Sharp-edged blocks of metamorphic shale lie embedded in a fine grained sandy to clayey detritus ("llampu"). These blocks may be tens of meters in diameter and commonly contain a network of quartz-wolframite veinlets. The detritus is more or less heavily cemented and has

become so solid that, for instance, the streams which cut the Tamiñani terrace are forming narrow cañons with vertical walls.

Wolframite occurs as fine grained disseminated fragments in the sandy or clayey material that vary in size from powder-fine particles to pieces several millimeters in diameter. The wolframite content of the breccias is very

FIG. 7. Ayopaya river and the terraces of the "Llamporas" seen from the Chicote Grande.

variable not only between different landslides but even within the same landslide. The richest ground was in the Tamiñani terrace formed by the fourth landslide. Based on the production over many years, the fine grained material is estimated to contain 0.2 to 0.24 per cent WO_3. Occasionally there are shoots of almost pure wolframite. The Perfeccionada terrace contains

on an average only 0.09 per cent of WO_3 and the frontal portion of the terrace of Huanupatilla, made up of material of the last (fifth) landslide, contains only traces of wolframite.

The wolframite concentrate contains 1 to 1.2 per cent tin in the form of fine grained cassiterite. Some barite may be present and rarely scheelite. The latter mineral has never been observed in the Chicote veins. At the base of the Tamiñani terrace large quantities of arsenopyrite were encountered associated with marcasite, which was formed, apparently, in recent times.

The llamperas are worked on a large scale in a series of open casts. Notwithstanding their very low metal content they are the lowest cost tungsten producers in Bolivia.

Investigations which were made recently in the bed of the Ayopaya river, below the llamperas, have shown the tungsten content of the river sands and gravels to be extremely low. This agrees with studies made in other parts of Bolivia which have shown that wolframite does not form alluvial deposits but is easily reduced, because of its excellent cleavage in 3 directions, to a powder that cannot be readily concentrated. On the other hand, the river sands showed a rather uniform content of cassiterite which has come not only from the deposits in the neighborhood of Chicote but also from Kami 10 km. up the river.

SUMMARY OF THE ORIGIN OF THE DEPOSITS.

During the Miocene period of principal folding of the Andes, and in the following periods, there were emplaced in the Central Cordillera region of Bolivia intrusive masses of granitic and quartz-monzonitic magmas. The small, isolated cryptobatholitic intrusion of Chicote is deep seated and has not been exposed by erosion. This igneous stock caused a local uplifting of the overlying sediments in the form of an anticline with attendant shattering. In the first phase of the formation of the deposit the pneumatolytic gases carried silicic acid and tourmaline from the magma into the roof sediments. In a second phase systems of small tension fractures developed in the massive, hard, contact-metamorphic sediments. Two general fracture systems are recognized, one system more or less normal to the long axis of the intrusive and occurring on the limbs, especially on the eastern limb, and a second system parallel to the axis of intrusion near the crest.

The filling of the fissures in the contact-metamorphic zone by hot hydrothermal tungsten bearing solutions was a single process. The mesothermal tin mineralization took place a little later and at a greater distance from the magmatic source. Locally there is a sharp demarcation of the two mineralizations. In part, the tungsten and the tin zones are separated by faults. Following the period of mineralization, the hard central contact-metamorphosed zone was further separated from the unmetamorphosed sediments by peripheral faulting.

Chicote is a hypothermal tungsten deposit of a worldwide type. It is distinguished from other geologically similar but older deposits by the fact that the magmatic source does not outcrop, but overlying sediments are pre-

served in great thickness and contain an abundance of veins. The wolframite veins were formed at high temperatures and at pressures that decreased upwards. The abundance of sulphides, especially pyrrhotite, is notable.

ACKNOWLEDGMENTS.

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DIRECCION GENERAL DE MINAS Y PETROLEO,
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STRUCTURAL AND STRATIGRAPHIC CONTROL OF ZINC DEPOSITS IN EAST TENNESSEE.

JOHNSON CRAWFORD.

ABSTRACT.

The East Tennessee zinc district is situated in the valley regions of the Appalachians. The outstanding structural features of the valley are folds and overthrust faults which have distributed the formations into a series of belts parallel with the long axis of the valley. The same formations, duplicated by thrust faulting, outcrop in each belt. All exposed formations are sedimentary, and most of the zinc occurrences are in the Knox dolomite or the Maynardville limestone. The ore mineral is sphalerite—lead free, and no other sulphides except minor amounts of pyrite. At present, all producing mines are in the upper 800 to 1,100 feet of the Knox dolomite, and are situated in Knox and Jefferson Counties. Five mines and two mills are in operation. The 4,000-ton Mascot mill of the American Zinc Company is supplied by ore from the Mascot, Grasselli, Athletic and Jarnigan mines. The 900-ton mill of the Universal Exploration Company is supplied by ore from its Davis mine near Jefferson City. Sphalerite is the sole primary ore mineral, and average tenors of crude ore vary from 2.5 per cent Zn to more than 5.00 per cent Zn.

The orebodies are of the replacement and breccia filling type and occur in disturbed breccia zones, which are approximately parallel to the bedding. In detail, however, this long axis may be inclined to the bedding strike. The principal structural features of the ore deposits are jointing, tear faulting, low angle thrust faulting, and bedding plane movement. Associated dolomitization is conspicuous. A major overthrust fault bounds the area in semi-circle. Within this compressive area tear fault zones are the vital structural features controlling the ore.

HISTORY OF DEVELOPMENT.

Zinc mining in East Tennessee had its beginning shortly after the Civil War when open cut operations were started on the oxidized outcrops of three ore deposits. One of these was at the Mossy Creek mine near Jefferson City where the ore occurs in the Kingsport limestone, a upper division of the Knox dolomite about 1,000 feet below the top of the formation. One was at Lead Mine Bend, near New Prospect in Union County, where the ore occurs in the Maynardville limestone, which is the upper phase of the Nolichucky shale. The third was situated at the Straight Creek Mine in Claiborne County, which also is in the Maynardville limestone.[1]

The open cut mining at Straight Creek, some 45 miles north of the Mascot-Jefferson City region, soon showed an obvious fault control of the ore shoots, and operations were projected into the sulphide zone where the high grade ore was mined to water level, and operations ceased about 1907. At Lead Mine Bend, the surface outcrop was large and the ore high grade. As at Straight Creek, a structural control of the ore by faults was soon apparent, and mining was extended along the faulted area into the sulphide zone until

1 Secrist, M. H.: Zinc deposits of Tennessee. Tenn. Division of Geology, Bulletin 31.

water level was reached. At this point mining above water level in lower grade ore, stratigraphically above the principal horizon, was attempted, but the mining was unprofitable, and operations terminated in 1901.

Operations at the Mossy Creek mine were spasmodic and short lived. As soon as the high grade surface ores had been mined and the sulphide zone encountered, the low grade tenor of the ore made mining operations unprofitable. But the mining had indicated a more extensive ore occurrence than in the other two localities. However, the structural control of the ore was obscure, and time and again, unsuccessful efforts were made to exploit the deposit, always with the same conclusion that the ore occurred in pockets and no clear picture of the structural control of the ore was obtained.

These three initial mining operations soon led to the exploration of other occurrences of zinc in East Tennessee. However, all of the mines now producing were developed in the upper Knox dolomite, and operations ceased on ore deposits in the Maynardsville limestone and the lower Knox dolomite. At Mascot and New Market, extensive ore deposits were developed, and furnished an opportunity to observe more widely the obscure structural control of ore deposits in the upper Knox.

In 1926, the Universal Exploration Company entered the district, and prospected the east flank of an anticline between Jefferson City and New Market. As the work progressed, certain fundamental structural conditions for the occurrence of commercial zinc deposits were indicated by the exploratory data. Some of the structural features were obtained by detailed surface mapping, others were made evident by surface drilling, but the data most vital to an understanding of the structural control of ore occurrence were obtained through underground observation.

Mining operations of the Universal Exploration Company at Jefferson City were started in January 1928 on oxidized ore. In May 1930, sulphide operations commenced. The orebodies were new discoveries resulting from three years of exploration work from 1926 to 1929.

OUTSTANDING STRUCTURAL FEATURES.

Diamond and churn drilling had blocked out sufficiently broad ore areas to indicate the presence of commercial orebodies. From this drilling much was learned as to the type of the orebody and it was evident that the occurrence of the ore was very complex, but just what the actual conditions were and what was to be the most suitable method of mining could only be determined by underground development. It was originally assumed that the ore bodies would be similar in occurrence to those at Mascot, located fifteen miles west, although the bulk of the ore at Jefferson occurs slightly lower stratigraphically than that at Mascot or New Market.

As exploration progressed, it became evident that selective mining would be necessary for the successful operation of the property. The orebodies did not lend themselves to broad mill hole methods of mining originally considered, but on the contrary, careful and selective mining of the ore offered many opportunities for reducing costs and actually producing a higher grade ore,

and incidentally for observing in great detail the control exercised by local structures upon mineralization. At present, mining operations are carried on by the heading and bench system and the broken ore is mechanically loaded by scraper hoists.

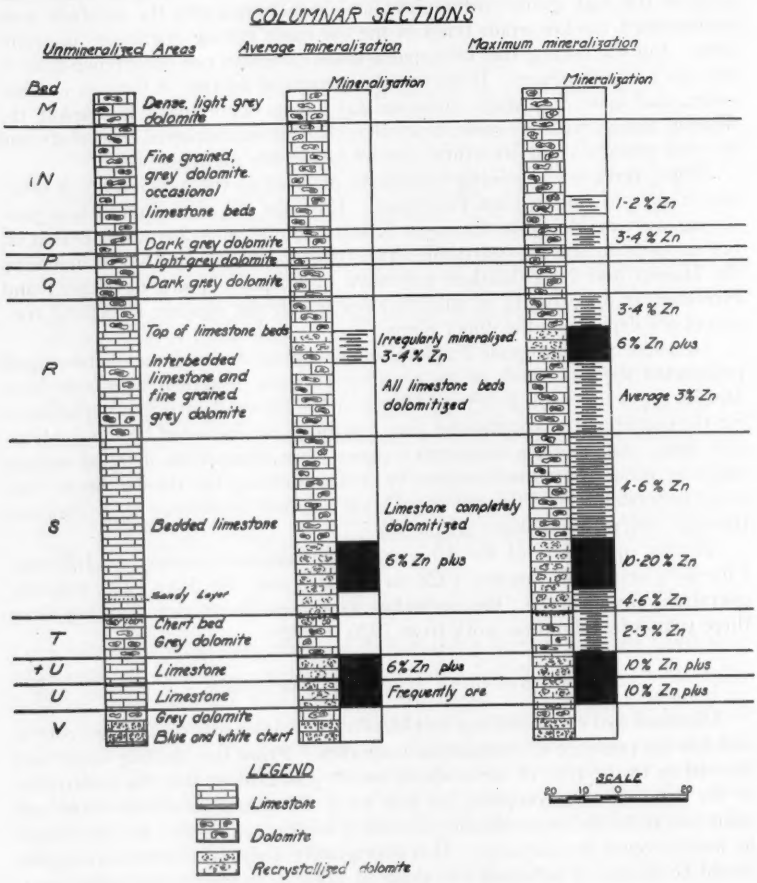

FIG. 1.

The ore deposit is mainly a replacement of dolomitized limestone by vein dolomite and sphalerite but ore minerals also fill fractures in brecciated dolomite. In shape, the individual ore shoots are rectangular to rhomboid and consist of ore blocks bordered by parallel sets of joints. As will be noted below in greater detail, two distinct ore horizons are recognized. The upper

productive horizon in the "R" and "S" beds (Fig. 1) attains a maximum thickness of 110 feet, with an average of 25 to 30 feet, and the lower ore horizon in the "U" beds has a maximum thickness of 18 feet with an average of 9 to 10 feet. The ore shoots in the upper ore horizons have their principal development down the dip, that is, in a S 30° E direction. Those of the lower horizon rake down the dip on a N 70° E course, and are elongated almost parallel to the strike with a slight down-dip component. The formation strike averages N 30° E, and the dip varies from 5° to 10° SE.

In detail the relation between the orebody as a whole and the individual ore shoots is complex. Within ore areas the formation is highly brecciated and intricately broken by countless joints and minor faults. Mineralization often terminates abruptly against a joint plane or fracture zone, one side being high grade ore and the other side barren country rock. Mineralization is usually strongest at the edges of the orebodies. There is no gradual decrease of values at the limits, but instead a sharp termination. There may be a change in ore elevation across a joint plane or fault zone, and there is often a narrow run of ore along the fault zone connecting the two horizons. This change in elevation across a fault is often in excess of any displacement of the formation and this discrepancy indicates that from one side of a fault to the other, there has been a change in the bed or beds selected for ore deposition. There are commonly sereval ore horizons superimposed one over the other.

The ore deposits at Jefferson City occur in brecciated dolomite, and the presence of any substantial limestone indicates that the margin of the ore is being approached. Two types of dolomitization are plainly recognized. One is the alteration of limestone to a coarsely crystalline dolomite, and the other is the alteration of limestone to a fine-grained gray dolomite. The difference indicated is probably due to different periods of dolomitization, rather than to various types of dolomitization affecting the beds contemporaneously.

The brecciated zones within dolomitized areas are considered to be thrust breccia marking an epoch of compression. The presence of a major overthrust fault which bounds the area as a great semi-circle presents an obvious source of compression. Within the compressive area, tear faults or fissures at an acute angle to the bedding are the vital structural features controlling the ore.

The structural features of thrust faulting and brecciation seem to affect only certain limestone beds and thin bedded dolomites, and seem to have no effect on the massive beds of dolomite above or below. The relatively undisturbed position of massive dolomite beds overlying areas of thick ore, is proof that minor thrust faulting and movement along beds localized the brecciated areas, rather than that structural deformation affected the entire thickness of strata.

It is evident that any mineralization of importance is confined to certain definite beds of dolomitized limestone, that the orebodies occur at intersections of these beds with one or more faults or fissures, and that the rake or trend of the ore zone will be related to the angle of intersection of the bedding and the fissure zone. Also it has been observed that for the orebody to have continuity, the angle of intersection of the formation strike and of the fissures should be fairly acute.

Within the area of the mine workings, no faults of any great displacement have been encountered. Several faults with 12 feet to 14 feet of displacement have been followed for long distances by stoping, and many fault zones with minor displacements ranging from a few inches to several feet are continuous over wide areas. These fault zones cut the formation at an acute angle to the strike; they make an obvious tear, and are plainly the outstanding and controlling structural feature of the ore zone.

The faults are of many types. Predominantly they are normal faults, and striations along the steeply dipping fault planes indicate a direction of movement varying from vertical through diagonal to horizontal. Low angle thrust faults occur frequently. For the most part, these do not cut through any great thickness of strata, but have a tendency to flatten and finally dissipate themselves in a gently dipping bedding plane. Movement along bedding planes is common. Often the bedding planes are filled with gouge and are deeply grooved by movement nearly parallel to the formation dip.

It is the writer's opinion that most of the faulting is pre-mineral. The occurrence of the ore is so intimately related to the faulting that any other opinion leaves no explanation for the presence of the ore. The direction of the faulting is one of the guide components for the direction of rake of the ore zones. The control of the ore by faulting is obvious, and it is a necessary part of mine development to work out the detail of the grids and blocks created by faulting.

It is true that certain faults considered by the writer to be pre-mineral show a definite crushing of the sphalerite along the fault plane. This post-mineral aspect of what is believed to be a pre-mineral fault is explained by a second period of movement along the fault zone. In a particular case which has been especially closely studied the failure to locate faulted segments of the orebodies precludes the possibility that they have been displaced by post-mineral faults, moreover the strike of the fault is also apparently the long dimension of the ore shoot, and this fact, too, presents a strong argument for the essentially pre-mineral nature of the faulting. Finally the ore is of a higher grade immediately adjacent to the fault zone, and silicification accompanying mineralization is more pronounced near the fault plane. These well established facts make it appear probable that there were several periods of movement along certain fault zones. The post-mineral phase of the movement represents the final adjustment of the mass after an epoch of compression and tearing.

RELATION BETWEEN STRATIGRAPHY AND MINERALIZATION.

The following stratigraphic description is based on observations underground, and on diamond and churn drilling on the properties of the Universal Exploration Company.

"M" Beds—not ore bearing (Fig. 1):

This consists of several hundred feet of massive beds of fine-grained light gray dolomite, and thin beds of "dove" colored limestone. This unit con-

tains numerous nodules and thin bands of blue chert, and occasional thin sandy areas. One sandy layer 6 inches to 12 inches, occurring 310 feet above the footwall bed, is reasonably consistent and is of value as a stratigraphic marker. However, the frequent occurrence of other thin sandy horizons complicates its identification, and the irregularity of its occurrence over wide areas leaves some doubt as to its dependability for correlation. When overlying thick ore the strata making up the "M" bed are often leached to a light chalky white color.

"N" Bed—not ore bearing—thickness 30 feet plus (Fig. 1):

Consists chiefly of fine-grained massive dolomite, darker in color than the overlying "M" bed. The presence of limestone beds within this formation usually foretells a similar lack of dolomitization in the calcareous beds making up the ore-bearing "R" and "S" beds below. These beds have irregularly occurring chert nodules, shale bands, and thin sandy layers, but no persistent horizon of any has been established in the "N" bed. When brecciated this unit may carry traces of sphalerite in fractures. There is reason to believe that alteration accompanying mineralization in underlying formations has completely dolomitized the "N" beds, which were originally a "dove" colored limestone.

"O" Bed—ore bearing—thickness 4 feet to 6 feet (Fig. 1):

A fine- to medium-grained dark gray dolomite, known as the "first black bed." This bed in the region of the mine is distinctive because of its dark color and has value as a horizon marker. Beyond the mineralized area, this bed is usually not as pronounced a "black," and apparently alteration accompanying mineralization has some bearing on the color. When brecciated, the bed may carry ore. It is the true hanging wall of the upper ore bearing measures.

"P" Bed—not ore bearing—thickness 4 feet (Fig. 1):

A densely granular very light gray dolomite. Its light color presents a striking contrast with the overlying dark colored "O" bed. When brecciated, the bed may carry traces of sphalerite.

"Q" Bed—ore bearing—thickness 6 feet to 9 feet (Fig. 1):

A medium-grained, sugary textured, dark gray dolomite, the "second black bed." Its color affords a striking contrast to the overlying light colored "P" bed. The succession of the "O," "P" and "Q" beds of prominent color variations furnishes an excellent stratigraphic marker.

"R" Bed—ore bearing—thickness approximates 40 feet (Fig. 1):

A series of interbedded limestones and dolomites with limestones predominating. In mineralized areas, the beds alter to a fine-grained brecciated dolomite, or to a coarsely recrystallized gray dolomite. When the "R" bed bears no ore, its alteration may be to a medium-grained dolomite or a slightly dolomitized limestone with minor amounts of silicification.

In areas of high vertical ore development, the entire thickness of the bed may contain minable ore. The first limestone ore bearing bed occurs nine feet below the top of this formation and this bed, for a 10 foot to 40 foot thickness, is a prominent horizon.

Nearly complete dolomitization of this bed seems to have been a necessary precursor or accompaniment for any substantial mineralization in the underlying "S" bed. Likewise the "R" bed seldom carries ore without a substantial thickness of ore in the "S" bed.

"S" Bed—principal ore horizon—thickness 55 feet to 60 feet (Fig. 1):

In its unaltered condition this formation consists of a thickness of "dove" colored limestone, with thin bands of green shale, thin sandy layers and nodular blue chert. Within five feet of the bottom a narrow band of sandy limestone occurs. This sandy layer is continuous over wide areas within mine workings and is a reliable horizon marker. However, occasionally it lacks continuity, and may be confused with sand bands occurring 15 feet to 20 feet above it.

The "S" bed is the most important ore horizon on the property, and contains by far the greatest tonnage of the known ore reserves.

In areas of thick ore, the formation is mineralized throughout. In areas of partial mineralization, the lowest 6 foot unit seldom carries ore. The most favorable horizon is from 6 feet to 20 feet above the bottom of the bed. Within ore areas, the formation is completely dolomitized, and the presence of any limestone is apt to indicate marginal mineralization.

Underground development shows that the ore bodies in the "S" bed and overlying "R" bed trend either N 30° W or N 70° W.

The limestone of the "S" bed has sharp lines of demarcation with its various phases of dolomitization. Stratigraphic thicknesses of as much as 30 feet of dove limestone locally were completely altered to various types of dolomite. Such alteration may be very abrupt, having taken place to completion with a distance of five feet horizontally. The change being along or near a joint or series of joints where there was no recognizable displacement.

"T" Bed—occasionally ore bearing—thickness 12 feet (Fig. 1):

The "T" bed is always gray dolomite and the grain varies from fine to medium. In areas of dolomitization, the overlying and underlying beds, which may have been dolomitized, are apt to make the indentification of the "T" bed difficult. In unaltered areas, however, the bed is distinctive, and thin bands of chert near the top are a reasonably constant characteristic.

This bed serves as a footwall for the upper ore horizon and is a definite hanging wall for ore in the underlying "U" beds. When correlated with the "U" beds, the "T" bed serves as an accurate horizon marker, and is the basis of correlation in the planning of mine development.

The "T" bed is seldom mineralized to a commercial grade, but when it is, it is usually indicative of ore in either the "S" or "U" beds.

"U" Beds—ore bearing—thickness 14 feet to 18 feet (Fig. 1):

In its unaltered state, this formation consists of thick-bedded "dove" colored limestone. Within ore areas, it has been altered to either recrystallized gray dolomite or fine grained gray dolomite.

Because of a peculiarity of mineralization, the formation naturally divides itself into two distinct horizons. The upper half of the formation, designated as the "plus U" bed, is 8 feet thick, and is the most consistently mineralized horizon in the north end of the Davis mine. The underlying part of the "U" bed is usually about 7 feet thick is less often mineralized than the "plus U" bed.

Mining has shown that either the "plus U" bed, the "U" bed, or both may carry ore within a given area. As a rule, the top 4 feet of the "plus U" bed carry the highest percentage of zinc. After crossing a fracture, the mineralization may immediately descend stratigraphically from the "plus U" bed to the "U" bed. This condition makes it necessary, when mining in the "U" beds, to keep a close check on stratigraphy because of the abrupt changes in ore conditions within the short stratigraphic distance of fifteen feet.

Developments to date, indicate that the ore bodies in the "U" beds have their principal development in a N 70° E direction.

Except along major axes of the orebodies, little ore is known to occur in the "R" and "S" beds which overlie extensive ore developments in the "U" formation. The north end stopes of the Davis mine and Community Lease are examples of this condition. Experience to date indicates that mineralization in the "U" formation is more persistent and of higher grade than in the upper ore horizons. "U" bed stopes have consistently acted as sweeteners to the mine grade. The "U" formation is the lowest known mineralized bed in this district.

"V" Formation—the footwall formation (Fig. 1):

Immediately underlying the "U" bed limestone is a fine- to medium-grained gray dolomite. Heavy bands of nodular blue and white chert occur three to five feet below the top of the bed. These cherts are distinctive, not because of their lithologic characteristics, but because of their massive occurrence. They have a thickness ranging from 4 to 7 feet. Experience has demonstrated that while these cherts are widespread, they are not a constant characteristic of the bed. For economic and stratigraphic purposes, these chert beds furnish a positive identification of the footwall. There are no chert horizons on the property comparable in their massive nature to the footwall flints. The underlying beds are essentially dolomite, with only thin limestone strata, and only in rarest cases has any mineralization been observed in them.

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UNIVERSAL EXPLORATION CO., Subsidiary of United States Steel Corp.,
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THE CULT OF THE INDETERMINATE.

WHITHER "REPLACEMENT"?

W. JAMES BICHAN.

FIFTY-FIVE years have now elapsed since John A. Church (1), in an excellent study of a precious metal quartz lode, submitted the thesis that much of the quartz in the veins had been emplaced by a process of *substitution* for masses of wall and horse rock. In other words, the rocks that had been afforded contact with the mineralizing fluids had been corroded by these in their passage. Later, how much we do not know, when the period of mineralization set in, the dissolution spaces were occupied by displacing solutions from which the mineral aggregate now apparent was able to crystallize. There is thus the supposition that before solutions capable of depositing quartz had entered the vein system, those that were traversing the host rock were understaturated with respect to certain of its constituents and subjected it to corrosive attack. If this process had taken place from a static body of solution then as the whole volume crystallized there would appear minerals containing all the elements that had been leached out of the wall rocks. This is not the case, so that it must be concluded that the attacking fluids, whatever may have been their relationship with the mineralizing solutions, had moved onward and upward through the fissures to permit entry of the metal-bearing fluids from the magma below.

It is unfortunate that the process of substitution was not completely clarified by Church at its inception in geologic literature. We would wish that he had suggested that the dissolution spaces bore the same relationship to the remainder of the country rock as the holes to the timber in a termite-ridden log, or as the air space to the skeleton of a sponge. The texture of the minerals of the ensuing period of deposition and crystallization mirror these same relationships, which are somewhat obscured, however, by the fact that the sections of silicified and altered wall rocks available for examination only present a two-dimensional view. The true conditions, as existing *in the solid,* have largely been ignored in extant interpretations of the phenomena.

Three years later, G. F. Becker (2), in a study of the same lode, threw doubt upon the concept of substitution on the grounds that the masses of country rock included in the quartz were angular, when they should be expected to be rounded (p. 387). Observing that the attack of the solutions upon the country rock was a selective process on a microscopic scale, Becker's objection consequently has no validity, and nothing is so much apparent that the horses of country rock have been silicified upon the lines suggested above. Becker recognized the limitations of his knowledge for he states (p. 288): "Of the actual precipitation of ore and gangue from solution little is known."

The term *metasomatic* appears to date from the same year (1879) in which Church proposed *substitution*. It was immediately taken up by Emmons (3) who was careful to define his terms (p. 565):

"By metasomatic interchange is meant an interchange of substance, without necessarily involving, as does pseudomorphism, the preservation of the original form of the substance replaced or even of its original volume."

This term *replaced* had first been introduced by Curtis (4) in his description of the mode of origin of the silver-lead deposits of Eureka, Nevada (p. 100):

". . . it would seem that the ore replaced the limestone very nearly bulk for bulk."

The use of *replaced* antedated the introduction of *replacement* by some three years. It was not until 1887 that Emmons summarized the developments in a paper to the American Institute of Mining Engineers and formalized the process as *replacement*, giving a decided bias in favour of the use of this word as against *substitution*, possibly on account of the terminology introduced by his colleague on the United States Geological Survey, J. S. Curtis in 1884.

The hypothesis introduced by Church was also taken up by C. M. Rolker, and in the same year as Emmons' adoption of the theory we find him referring to the Leadville ore deposits as (5):

". . . the products of a substitution process, between the mineral solutions on the one hand and the carboniferous limestone on the other."

This preoccupation with the thought that the dissolution of the host rocks to form spaces wherein the existing deposits might crystallize has persisted to the present day, regardless of whether the minerals missing from the host rock appear in some form in the end product.

Emmons paper of 1887 (6) contains the statement that:

"The possible application of the theory of the formation of ore-deposits by replacement or substitution is almost unlimited."

While admitting that:

"The process is most readily conceivable in the case of easily soluble rocks, like limestone and dolomite."

Emmons was not to be deterred from suggesting to the world at large that:

"The theory of formation of ore-deposits by replacement, as opposed to the filling of pre-existing cavities, may, however, be applied to deposits in rocks which are not so readily soluble as limestone, in which cases the percolating solutions would have first attacked the relatively more soluble among their constituents."

The foregoing statements have been in the nature of a universal touchstone for the hypothetical transmutation of rocks into ore, of the less valuable into the more desirable minerals, and in fact of any original rock type into any ore that appears to be where the rock was before. Wherever geologists have encountered baffling and inexplicable conditions in the sphere of ore formation, they have fallen back countless times on this wonderfully inclusive term: *replacement*. The older geologists took more pains in their thinking, taxed

their intellects more, and Emmons characteristically keeps his exact meaning clear (6, p. 127):

"By metasomatic interchange, I understand an interchange of *substances*, but not necessarily molecule by molecule, in such a manner as to preserve the original structure, form or volume of the substance replaced."

While the results of the process were obvious enough to Church, Curtis, Emmons and Rolker, they all realized that its mechanism had yet to become perfectly understood.

The seed having been sown, as it were, little further developed until 1893, when Posepny (7), while taking cognizance of the trend of thought amongst American economic geologists, held firmly to practical considerations:

". . . we must assume that the liquid which formed the space of dissolution also performed the filling; in fact that both processes were almost contemporaneous. Nevertheless they must not be confounded with metamorphic processes where the idiogenite is expelled, atom by atom, by the xenogenite; for the deposits in spaces of dissolution show always a distinct crustification, and hence every single crust, at least, must have found free space waiting for it."

Although his experience was limited to crustified deposits, Posepny was thus clear upon the basic fact that replacement processes did not involve contemporaneous dissolution and deposition. He recognized the processes as being almost contemporaneous, *i.e.*, that deposition followed closely upon the cessation of corrosion and that the two stages were but part of a continuous sequence of dynamic events leading to the formation of ore. Posepny preferred "spaces of dissolution" to "spaces of corrosion," brought into being by the leaching and attacking qualities of the mineralizing liquids or fluids. One thing which should have been made thoroughly clear at this point was the absence of any open space intervening between the phases of dissolution and deposition. The so-called open spaces were always completely filled with dissolving or mineralizing fluid, or fluid of some character, and the passage from dissolution to deposition conditions may readily have been brought about in all probability by a successive lowering of the temperature of the host rocks. It can now be asserted that crustification has other implications than the commonly assumed one of signifying and being essential to the previous activity of a process of open-space filling.

In the discussion of Posepny's paper, Church (8) stated:

". . . one of the surest advances which vein-geology has made in the last fifteen years has been the steady growth of the idea that the thickest ore-bodies may have been formed by the replacement of masses of wall-rock fragments, or by the spread of siliceous replacement from a narrow crevice through the walls."

Becker, in his contribution to the discussion (9), still appeared to have been at odds with Emmons' twice clearly defined conception:

"The theory of the substitution of ore for rock is to be accepted only when there is definite evidence of the pseudomorphic, molecular replacement."

This divergence of opinion between the devotees of the theory of replacement has persisted to the present time. When asked to express their opinion

on the exact mode of operation of the mechanism of replacement, a dozen different geologists will give as many different views of this ephemeral process, though each will have no doubt in his mind as to its validity, and will feel perfectly sure that the other eleven know *exactly* what he means when he talks of replacement.

Unfortunately for the profession, while it may be crystal-clear to a certain class of geologist that he means something definite by replacement, the significance is by no means so apparent to those concerned with making the decisions of the expenditure of money on the development of ore reserves ahead of production. It is to be doubted that the application of the replacement theory has ever yet found one ton of ore. Its application to concrete problems is rarely tried since it does not stand up to the type of question as: will there be ore in such-and-such a block of ground.

Despite the lack of an economic application of the confusion of ideas embodied in the theory of replacement, it had, by 1905, been accepted by the geologists of the United States Geological Survey, including Boutwell, Spurr, and Lindgren, as a process of ore deposition. Boutwell (11), in regard to Bingham decided that:

". . . ore was deposited by molecular replacement"; while Lindgren adopted a more cautious attitude. The latter (12) defined his mechanism:

"Metasomatic processes are those by which, through chemical reactions, and mainly by aid of water, one mineral is changed into another."

"Where a certain time intervened," Lindgren proposed that "the process is a mechanical one and should not . . . be considered metasomatic." Thus early he arrived at the important distinction that has since become obscure in the minds of many who have applied the term replacement to ore deposits that they have described. Lindgren maintained the distinction established by Posepny twelve years earlier, but since he did not stress the matter with sufficient force, we have today reached a stage where replacement is one of the most overworked words in the language of economic geology, not excepting *magmatic,* but lacking its specific connotation.

During the early part of the century thought became crystallized along lines that involved a series of chemical reactions for the processes of replacement, following a lead given by Lindgren, and of a more popular character than that suggesting the mechanical relationship:

". . . it may sometimes be difficult to decide whether a replacement is effected by separate dissolving and filling, or by one of several chemical reactions."

Numerous abortive attempts were made to reconcile quantitative chemical reactions with the preliminary and end products found in certain localities. The negative success in these ventures allowed this trend to lapse, and there it has remained in abeyance ever since.

Becker remained alone in demanding (9) pseudomorphism and molecular replacement as cornerstones of the argument. Emmons' conception of metasomatic interchange prevailed (3, p. 565), and it is in the latter sense and definition that the theory of metasomatism, or metasomatic replacement, or simply replacement, has become stabilized over the course of the years.

One can hardly consider that the theory has developed, apart from the ever-increasing number of deposits that have been taken into the fold and set up as shining examples of replacement, or more frequently "hydrothermal" replacement. Even mineralizations having the high degree of respectability of magmatic segregations have been pried from their surroundings and dubbed "replacements."

There is essentially no change between the present-day ideas of the process and those of fifty years ago; neither has there been any considered attempt to amplify the workings of the supposed natural phenomenon. The precise mechanism and sequence of events has been left to the imagination and the history of the most interesting and informative stages in the life of an ore deposit has been left entirely inconclusive.

The importance of Lindgren's recognition of *mechanical replacement* as a possible mechanism of ore formation, an alternative to molecular, pseudomorphic, or metasomatic "replacement" has yet to be fully recognized. The former concept appears to have disappeared through the years, but it is nevertheless the one that the writer considers to have been most commonly operative. Of the early writers, there is nothing in Spurr's monograph (13), nor in the mass of his subsequent work, which would indicate that his conception of "replacement" was other than a purely mechanical one.

The time has arrived when we are compelled to extend our ideas concerning the modes of mineralization, and to broaden the field of postulation beyond the elementary stages of the late nineteenth century. The demand for mineral products will require a drastic revision of our thinking and of our technique if the limited nucleus of trained and experienced economic geologists, of whom not all are mining geologists in the truly practical sense, are to fulfil their utmost usefulness and perpetuate the industry by successfully answering all calls on them to find ore.

We may still safely speculate with J. S. Curtis (4):

1. "that the ore was precipitated from the solutions in pre-existing large openings" although it is still far from being widely recognized that hydrothermal solutions, once thought to be the universal ore-carriers, have but a limited application in the processes of ore formation.
2. "that it (the ore) was substituted directly . . . rock being dissolved and metallic minerals being left in its place," or we may admit with Waldemar Lindgren (10) that it is: "metasomatism" (for as much practical benefit as we may expect to derive from the thought), and
3. "cavities of dissolution subsequently filled" (mechanical replacement).

Proceeding to a rationalization of these early divisions of thought, we can set up a classification that will include all known types of introduced ore deposit:

I. ore precipitated or separated from solutions or melts, or crystallized from melts, and deposited in pre-existing openings of mechanical origin, i.e. fractures or openings of large size that have been formed in response to stresses of the nature of tension, torsion, or shear.

II. ore precipitated or separated from solutions, or melts, or crystallized from melts, and deposited in pre-existing openings of chemical origin, *i.e.* dissolution spaces and chambers formed as a result of the attack of natural fluids that are undersaturated with respect to some or all of the mineral constituents of the host rocks.

This constitutes a practical mining geologist's classification, taking account of the larger problem of the origin of the ore receptacles.

It is at once appreciated that ore may be precipitated from solutions or melts as a result of pressure or temperature changes, or the addition of certain solid components to the phase system, or by the intermingling of solutions of different character. It may also become separated from solutions or melts, *e.g.* on account of mutual immiscibility. Finally the entire substance of a melt may become crystallized and thereafter constitute ore, although a process of segregation on a large scale may have preceded consolidation.

Ore minerals that have separated from solutions or melts may crystallize either before or after the mass of the gangue minerals that are associated with them.

We should be prepared to visualize the circumstances wherein attacking magmatic fluids have formed large and suitable receptacles for ore by the selective penetration of host rocks.

Ore deposition in prepared fractures, cavities, or chambers, may have taken place from the attacking fluids, where the receptive spaces were formed by chemical means, or from fluids of a different character and position in the time scale that had displaced them from these spaces. The cases must also be considered where disseminated ores have been formed because the displacing fluids have contained minerals of value in suspension, either as crystals or crystalline aggregates, or as fluid globules (Newhouse—15).

Selective penetration of host rocks by attacking fluids is perhaps the "infiltration" of Barrell (4).

Where separate dissolving and filling have been operative, as is believed to have been so in the majority of cases, it is submitted that it would be scientifically correct to say that the ores had been formed by *displacement:* a significant term to indicate Lindgren's mechanical process. The term "replacement" may properly be confined to its proper usage to include the processes of pseudomorphism as recognized by Lindgren and geologists generally.

A thorough restudy of modes of origin assigned to many ore deposits is indicated. Where the term "replacement" has been used without clear definition of its implication it should be expunged from the literature. Now is none too soon to clear away the loose descriptions that have characterized many of our past efforts, and to make a fresh start on a truly scientific trend of thought in regard to the origin of ores.

The so-called "replacement" deposits of high temperature origin have normally been characterized as "irregular," "sporadic," "erratic" and "capricious" (16), terms which are none too helpful to an executive charged with laying out a development programme.

A very few significant facts have appeared during the course of numerous studies of the limestone "replacements." Umpleby (17) demonstrated that ore tends to occur on the "limestone side" of the contact zone and came to the conclusion that: "The cause of the control is essentially chemical" (p. 64).

The capacity of the magma or magmatic fluid to infiltrate the limestone selectively with respect to other formations, and therein to form chambers and large irregular cavities conforming more or less to the bedding planes, can be seen in numerous cases. Mineralizing fluids subsequently displace the attacking magmatic liquids and effect ore-deposition, although the access channels are not always large nor obvious. The latter are not always needed as numerous instances occur where ores have been derived by peripheral segregation and infiltration through a limestone environment from its contact with a still fluid porphyry. The ore fluids displace the porphyry magma, especially at embayments of the contact within the limestone formations.

At Iron Springs, Utah, ". . . the largest and most numerous bodies of ore are in limestone along the contacts with the porphyry" (16). The limestone has been largely corroded by the porphyry magma, the latter having been displaced by magnetite to form an ore body 1,400 feet long by 300 to 500 feet wide, and the ore is known to extend downward at least 300 feet. In addition to the peripheral ore bodies in the limestone, vertical lenses of magnetite occur well within the porphyry masses. The veins "are usually somewhat curved, tapered at one or both ends, are almost invariably branching, and are accompanied by subsidiary parallel fissures. They have no common course, and in general follow the directions of adjacent joints and faults. They are thought to be contraction fissures produced by tensile stresses set up in the cooling porphyry." It is suggested that these lenses are in reality arrested trains of magnetite crystals, caught in the process of being segregated towards the periphery of the porphyry mass by flotation phenomena associated with the escape of volatiles from the magma. That they are not fissure veins is proven by the fact that the jointing in the porphyry (one of its earliest formed characters after cooling and crystallization) has not been mineralized at all. If these were fissure veins, then some at least of the joints would have become mineralized at the same time by any solutions appearing during the subsequent history of the mass of porphyry. The reference (16) further states that "It is clear from the field facts that . . . the ore was introduced (into the limestone) after the outer shells of the porphyry masses had solidified." That is to say: where the porphyry magma was abutting against sandstone, with whose major constituent (silica) it was already supersaturated, it would proceed with its crystallization. Against limestone the porphyry would continue to have its fluidity maintained for a further period due to the dissolved carbonate elements with which it would continue to be undersaturated long after the marginal facies against the sandstone had started to crystallize.

At Cornwall, Pennsylvania (16, p. 65) the "more shaly, magnesian beds were selectively replaced and are richer in magnetite than the non-argillaceous beds," a feature that suggests chemical control to have been effective to some extent in localizing the ore deposition.

At Concepción del Oro, Mexico (16), "copper deposits . . . occur along both the east and west contacts of a granodiorite intrusive." It is stated that the "margin of the granodiorite was transformed into garnet rock, in which the garnet, along with diopside, wollastonite, quartz, and minor calcite forms pseudomorphs after plagioclase, hornblende, and pyroxene." It is suggested that this *apparent* pseudomorphism is indicative of (1) *corrosion* of plagioclase, hornblende, and pyroxene upon the accession of lime to the interstitial fluid from the limestones; (2) deposition of various groundmass minerals in these corrosion pools as crystallization proceeded, thus forming the typical garnet rock.

Apparently some investigators of this class of deposit have been able to follow an independent course of thinking for the same reference (16, p. 72) mentions that the "dike-like habit of the calcic silicate masses has caused some pyrometasomatic deposits to be classed as *igneous*." This observation refers to the work of C. W. Wright (18).

The pyrite deposits in the southern part of Spain exhibit characteristics somewhat akin to those at Iron Springs, Utah, the principal difference being that the ore minerals are mainly the metallic sulphides, although there is a very subordinate amount of magnetite. The same arrested progress of trains of ore mineral within the crystallizing porphyries is apparent. The massive sulphide ores have crystallized in apophyses formed by the upward pentration of the phase contact between the porphyry and the overlying rocks, or in large elliptical chambers formed by torsional stresses in the crust rocks at the time of maximum porphyry penetration.

These are but a few examples of large tonnage and other propositions that have been loosely classed as "hydrothermal replacements"; all such deposits present a challenging opportunity for restudy, and favorable ground for the rehabilitation of former mining fields.

BOURLAMAQUE, QUEBEC,
April 30, 1945.

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RALPH E. DIGMAN.

Pennsylvania's Mineral Heritage. Pp. 248; Figs. 29; Pls. 22. Penn. Dep't of Internal Affairs and Penn. State College. Harrisburg, 1944. *Here is a bountiful volume dealing with the economic mineral deposits of the Keystone State. It was prepared jointly by the Pennsylvania Topographic and Geologic Survey and the School of Mineral Industries of the State College and was supervised by a committee consisting of G. H. Ashley, State Geologist; Edward Steidel, Dean of the School of Mineral Industries; and others. The study is in three parts, statistics of the mineral industries, mineral resources, and technology and trends in the mineral industries, and has an 8½" × 11" page size. Copies may be purchased from the Division of Documents, Department of Property and Supplies, Harrisburg.*

Oil and Gas in Eastern Kansas. JOHN M. JEWETT AND GEORGE E. ABERNATHY. Pp. 244; Figs. 21; Pls. 4; Tables 91. Bull. 57, Kansas Geol. Survey, Lawrence, 1945. *"This report constitutes a summary of the results of past work and a preface to important future work on the occurrence and development of oil and gas deposits in eastern Kansas. The history of petroleum development covers a span of 85 years." The 43 counties constituting eastern Kansas are dealt with separately and four east-west cross-sections illustrate the subsurface geologic conditions and show the importance of the Nemaha "ridge" and other structural elements.*

Stratigraphy of the Marmaton Group, Pennsylvanian, in Kansas. JOHN M. JEWETT. Pp. 148; Pls. 4; Tables 2. Bull. 58, Kansas Geol. Survey, Lawrence, 1945. *This is the first of several unit descriptions of Kansas Pennsylvanian rocks planned for publication. The Marmaton group is Desmoines in age and consists of four limestones and four shale formations. The stratigraphy of the group is described in detail and the group is used as evidence of cyclic deposition.*

Selected Well Logs in the Virginia Coastal Plain North of James River. D. J. CEDERSTROM. Pp. 82; Fig. 1. Circular 3, Virginia Geological Survey, University, 1945.

U. S. Bureau of Mines, Washington, 1945.

Metal- and Nonmetal-Mine Accidents in the U. S., 1942. W. W. ADAMS AND F. J. KENNEDY. Pp. 81; Figs. 19. Bull. 461. Price, 20 cents.

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Accident Statistics as an Aid to Prevention of Accidents in Bituminous-Coal Mines. Coal-Mine Accident-Prevention Course, Section 1. Pp. 40; Figs. 13; Tables 10. Miners' Circular 47. Price, 10 cents.

Accident Statistics as an Aid to Prevention of Accidents in Metal Mines. Metal-Mine Accident-Prevention Course, Section 1. Pp. 26; Figs. 5; Tables 7. Miners' Circular 51. Price, 10 cents.

Accidents from Falls of Rock or Ore in Metal Mines. Metal-Mine Accident-Prevention Course, Section 2. Pp. 53; Figs. 43; Tables 4. Miners' Circular 52. Price, 10 cents.

Carbonizing Properties and Petrographic Composition of Hazard No. 4 Coal from Columbus No. 4 Mine and High-Temperature Carbonizing Properties of Hazard No. 7 Coal from Hardburly Mine, Perry County, Ky. J. D. DAVIS AND OTHERS. Pp. 46; Figs. 23. Tech. Paper 672.

Reserves, Bed Characteristics, and Coking Properties of the Willow Creek Coal Bed, Kemmerer District, Lincoln County, Wyo. A. L. TOENGES AND OTHERS. Pp. 48; Figs. 14. Tech. Paper 673. Price, 25 cents.

Detonators: Initiating Efficiency by the Miniature-Cartridge Test. R. L. GRANT AND J. E. TIFFANY. Pp. 34; Figs. 13. Tech. Paper 677. Price, 25 cents.

Case Histories and Quantitative Calculations in Gravimetric Prospecting. DONALD C. BARTON. Pp. 49; Figs. 16. Tech. Pub. No. 1760, Am. Inst. Min. and Met. Engineers. New York, 1944.

Quantitative Spectrographic Determination of Minor Elements in Zinc Sulphide Ores. LESTER W. STROCK. Pp. 22; Figs. 12. Tech. Pub. No. 1866, Am. Inst. Min. and Met. Engineers. New York, 1944.

Forêts et Déserts. C. L. SAGUI. Pp. 25. Extraits du *Bulletin de la Société d'Étude des Sciences Naturelles de Vaucluse,* Nos. 1 and 2. Avignon, 1944.

Report on Exploration for Oil in British Guiana. H. G. KUGLER AND OTHERS. Pp. 78; Figs. 6; Enclosures 4. Bull. 20, Geol. Survey of British Guiana. Georgetown, Demerara, 1944. Price, $1.00.

SOCIETY OF ECONOMIC GEOLOGISTS

Annual Meeting, December 27–29, 1945, at Pittsburgh, Pa.

It has been customary for the Society to hold it annual technical sessions jointly either with the American Institute of Mining and Metallurgical Engineers or with the Geological Society of America. As the Geological Society, which has not met since 1941, is resuming its annual meetings at Pittsburgh this December, it has been decided by the officers of the Society of Economic Geologists to unite with the Geological Society and the affiliated groups in this first post-war meeting. This decision is in accord with instructions issued by the Council of the Society of Economic Geologists at its February (1945) New York meeting.

Full details regarding the program of the proposed meetings have not yet been perfected. When they are completed, notice will be given both in this journal and in special communications sent to all members.

Tentative plans include several symposia dealing with outstanding problems facing the profession, many of which are immediately related to economic and other forms of applied geology. For such symposia, speakers will be invited and time will be specially allotted to discussion from the floor.

Some time will also be available for geologists to present, at their own election, papers dealing with subjects of current interest and special importance in the field of applied geology, including all phases of economic geology. Any person wishing to present such a paper should communicate at once with the Chairman of the Program Committee (Dr. J. W. Peoples, U. S. Geological Survey, Washington 25, D. C.) or with the Secretary of the Society (Room 411, Schermerhorn Hall, Columbia University, New York 27, N. Y.) requesting the usual blank for abstracts; submission of this blank is essential before a paper will be considered for the program. The Program Committee may find it necessary, for want of program time, to select the papers to be thus presented, listing others by title, for later publication. *Closing date for receipt of all abstract forms will be November 1st.*

In addition to the technical papers and the symposia mentioned, the sessions will include the Annual Meeting of the Council, a luncheon of the Society, the Annual Business Meeting, and the Address of the retiring president, Dr. O. E. Meinzer.

Joe W. Peoples,
Chairman, Program Committee.

Chas. H. Behre, Jr.,
Secretary.

September 27, 1945.

SCIENTIFIC NOTES AND NEWS

HORACE FRASER has resigned from the Metals and Minerals Division of the F.E.A. to become Manager of the Falconbridge Mine, at Sudbury, Ontario.

W. E. WRATHER, Director of the U. S. Geological Survey, has returned from a trip to Alaska.

JOSEPH B. UMPLEBY announces change of address from 4544–55 N.E., Seattle 5, Washington, to Continental Building, Dallas 1, Texas.

ALFRED K. SNELGROVE, chairman of the Department of Geological Engineering of the Michigan College of Mining and Technology and geological consultant to the government of Newfoundland, has been appointed professor of geology at Rutgers University and director of the newly-organized Bureau of Mineral Research there. The Bureau will undertake a geological and ceramic study of the State's mineral resources. Dr. Snelgrove will work in close cooperation with State Geologist Meredith E. Johnson who has been named as a research associate in geology at Rutgers. A detailed plan for the mineral resources study has been prepared by Paul M. Tyler, mineral economist on leave from the U. S. Bureau of Mines.

It is reported that a discovery by a New Zealand chemist showed that serpentine, mixed with commercial superphosphate, produced a superior fertilizer at a lower cost to the farmer.

High-grade bauxite float has been found by the Oregon Department of Geology and Mineral Industries in several localities both north and south of Salem, Oregon. Pieces of this float, made up largely of gibbsite, a well known bauxite mineral, are scattered widely over the surface, and also occur as nodules distributed in the overburden at places in the southern part of the Eola Hills and in several localities in the Salem Hills. Chemical analyses of this float show 50 to 60 percent alumina, 1 to 13 percent iron, and 2 to 6 percent silica. The Department has been searching for and investigating bauxite deposits for over a year.

R. R. SAYERS, Director of the U. S. Bureau of Mines, said today that a survey indicated that areas favorable to the occurrence of petroleum exist in lower Florida. Several oil companies have leased land and started exploration work in that region.

DR. WARREN J. MEAD of the Massachusetts Institute of Technology, who has been on leave of absence to serve as Director of Reynolds Research at Glen Cove, Long Island, during the war period, has resumed fulltime duties as Head of the Department of Geology at M. I. T. He will continue to act as research consultant for the Reynolds Metals Company.

As this issue goes to press, newspapers announce that $1,000,000 will be expended by Reynolds Metals Company for a research laboratory on Memorial Drive, Cambridge, Mass. The Boston area was selected because of availability of personnel and materials for research purposes.

MR. A. C. SKERL was recently released from internment in the Philippines and is now geologist for the Kenville Gold Mine, Box 390, Nelson, British Columbia, Canada.

W. E. WRATHER, Director of the U. S. Geological Survey, stated that formations of Paleocene and Eocene offer some promise of oil production from deep zones in the northern part of the Los Angeles basin. The only well in the basin to penetrate these rocks had good shows of oil, and additional testing of these formations is warranted. As a guide to the identification and correlation of these formations in future wells, geologists of the Geological Survey have just completed a study of the stratigraphy and paleontology of these rocks in the northwestern part of the Santa Ana Mountains, which is the only area of outcrop bordering the basin where formations of both series are known to be present.

ALAN M. BATEMAN has resigned from the F.E.A., effective November 1, 1945, where since May, 1942, he has been in charge of development and procurement of all foreign metals and minerals needed for the war effort.

H. E. MCKENSTRY has resigned as Chief of the Minerals Division of the Metals and Minerals Divisions of the F.E.A., effective November 1. After a brief interlude he will take up his new duties at Harvard University.

CARL TOLMAN has resigned his position with the Minerals Division of the Foreign Economic Administration and has returned to Washington University, St. Louis, Missouri, as Professor of Geology and Head of the Department.

LOUIS W. WRIGHT has returned to San Francisco from Chile where during the war he has represented the F.E.A. at its cost operation of Andes Copper Co. at Porterilloo, Chile.

WILLIAM KANE has resigned as Chief of the Mineral Staff of the F.E.A. in Mexico to become consultant in mineral matters to the Bank of Mexico, Mexico City.

JAMES DOUGLAS has resigned as Deputy Vice President, Metals and Minerals, War Production Board, effective September 1.

R. C. ALLEN is now Vice President in charge of Metals and Minerals, War Production Board.

LT. COL. M. T. HALBOUTY, former Houston consulting geologist and petroleum engineer, has been released from active duty and will resume his consulting practice in geology and petroleum engineering at the Shell Building, Houston.

DR. E. L. BRUCE was in the Yellowknife and Great Bear lake areas of the North West Territories during the summer.

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SOCIETY OF EXPLORATION GEOPHYSICISTS

Announcement is made of the appointment of a new Business Manager for the Society to succeed J. F. Gallie, whose other duties have forced his resignation. Editorial matters, as heretofore, will be handled by Dr. L. L. Nettleton, P. O. Box 2038, Pittsburgh 30, Pennsylvania. All other correspondence should be addressed to the attention of

E. STILES, BUSINESS MANAGER
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Aerial Photographs and Their Application. By H. T. U. SMITH. Figs. 61. Pp. 372	$3.50
Aerial Photographs: Their Use and Interpretation. By A. J. EARDLEY. Pp. 209	2.75
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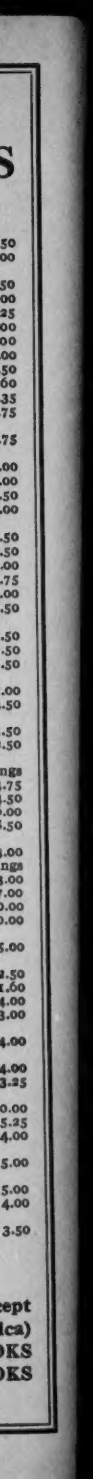
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